UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE OUTLET WORKS KEYHOLE DAM--BELLE FOURCHE UNIT, WYOMING MISSOURI RIVER BASIN PROJECT

Hydraulic Laboratory Report No. Hyd-338

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

September 15, 1952

FOREWORD

Hydraulic model studies of the outlet works for Keyhole Dam, Belle Fourche Unit, Wyoming, Missouri River Basin Project, were conducted in the Hydraulic Laboratory of the Bureau of Reclamation at Denver, Colorado, during the period June 1949 to July 1950.

The final plans, evolved from this study, were developed through the cooperation of the staffs of the Spillway and Outlets Section No. 2, the Mechanical Section, and the Hydraulic Laboratory.

During the course of the model studies, Messrs. H. W. Tabor and R. H. Whinnerah of Spillway and Outlets Section No. 2 frequently visited the laboratory to observe the model studies and to discuss test results.

These studies were conducted by W. E. Wagner and R. H. Slykhouse under the supervision of Messrs. A. J. Peterka and J. N. Bradley of the Hydraulic Laboratory staff.

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Laboratory Report No. Hyd-338
Hydraulic Laboratory Section
Compiled by: W. E. Wagner
Reviewed by: A. J. Peterka

Subject: Hydraulic model studies of the outlet works--Keyhole Dam--Belle Fourche Unit, Wyoming--Missouri River Basin Project

SUMMARY

The hydraulic model studies discussed in this report were made to determine certain flow characteristics of the regulating gate, to study the flow distribution in the tunnel downstream from the gate chamber, and to check the performance of the stilling basin. The results and conclusions contained herein are based on tests conducted on a 1:20 scale model of the Keyhole Dam outlet works, Figure 4, and a 1:9.75 scale model of the slide gate, Figure 6.

As a result of these studies, the splitter wall immediately downstream from the gate chamber was redesigned and a ridge along the tunnel invert was developed to smooth the flow before it entered the stilling basin.

Four different splitter walls, Figure 9, were tested. In general, the recommended wall consisted of lengthening the preliminary wall by 18 feet to provide more uniform flow in the tunnel downstream from the gate chamber, Figure 9c. To aid in distributing the flow more uniformly over the tunnel width, a ridge 7.5 inches high was installed on the tunnel invert, Figure 10d.

Studies of the stilling basin operation revealed that the basin proper was adequate and would perform satisfactorily when the flow was evenly distributed before it entered the stilling pool. Relatively uniform flow at the stilling basin entrance was obtained by installing the ridge described above and lengthening the horizontal section between the end of the tunnel and the origin of the trajectory curve, Revision No. 5, Figure 10d.

The performance of the recommended basin was satisfactory at all flows. Figures 14 to 19, inclusive, show the operation of the recommended design at different gate openings and for normal and maximum reservoir elevations.

Water-surface profiles in the stilling basin and scour tests of the recommended design are shown in Figures 20 and 21, respectively.

Pressures were obtained in the bellmouth entrance to the gate chamber, along the trajectory curve in the stilling basin, and at two points along the ridge in the tunnel. Results of these tests, shown in Figures 22 to 24, inclusive, show that the pressures were satisfactory.

The 1:9.75 model of the slide gate was used to study the flow conditions within the downstream gate frame. Tests on this model indicated that subatmospheric pressures could be expected in the roof of the downstream gate frame if the gate were operated at openings above 98 percent. These studies are discussed on page 5.

INTRODUCTION

Keyhole Dam is a part of the Cheyenne Division, South Dakota-Wyoming, Missouri River Basin Project, and is located on the Belle Fourche River about 16 miles northeast of Moorcroft, Wyoming, Figure 1. The dam is an earth-fill structure approximately 3,420 feet long and has a maximum height of about 165 feet above the lowest foundation.

The spillway, which is a concrete open channel with an uncontrolled crest 19 feet 3 inches in length, is designed for a maximum discharge of 10,800 second-feet and is located on the right abutment of the dam, Figure 2. The outlet works is located near the left dam abutment and is designed for a maximum discharge of 900 second-feet at reservoir elevation 4070 and 1,500 second-feet at maximum reservoir elevation 4128.1.

The outlet works consists of a trashrack structure and entrance transition, a concrete-lined tunnel 9 feet 6 inches wide and 8 feet 3 inches high with a semicircular arch roof, a gate chamber, and a stilling basin. Flow through the outlet works is controlled by two high-pressure slide gates, 3 feet 6 inches square, located in the gate chamber near the center of the dam, Figure 2.

The hydraulic model tests discussed in this report were made to study the flow conditions in the tunnel downstream from the slide gates and the stilling basin performance.

THE MODELS

The 1:20 Model

The model of the outlet works was built to a geometrical scale of 1:20 and consisted of a head box used to represent the reservoir, a section of tunnel leading to the gate chamber, two slide gates 1.95 inches square, a transparent tunnel 12.4 feet in length, the stilling basin, and a section of the channel downstream from the basin, Figure 4. The outlet tunnel between the reservoir and the gate chamber was not modeled since this portion of the tunnel flows under pressure and no hydraulic problems are anticipated upstream from the gate chamber. The tunnel upstream from the gate chamber was represented by a 4-foot length of pipe formed from sheet metal and equipped with a 4-vane flow straightener at the upstream end.

The slide gates, gate chamber, and tunnel downstream from the gate chamber were constructed of transparent plastic to permit observation of the flow conditions in the tunnel portion of the outlet works. Flow through the model was controlled by raising or lowering the gates by means of a threaded gate stem machined from brass rod, Figure 7a.

The head box, stilling basin, and downstream channel were constructed of wood and lined with galvanized sheet metal. The trajectory curve and basin floor were made of smooth concrete formed to metal templates and the downstream channel was formed with pea gravel approximately 8 inches deep. A plate glass panel was used as one basin training wall to permit observation of the stilling action in the basin. Piezometers were installed along the trajectory curve on the center line of the basin, Figure 24.

Water to the model was supplied by one of the portable laboratory pumps and metered through a combination venturi and orifice meter. Tailwater elevations in the stilling basin were controlled by a tailgate located at the downstream end of the model and were set according to the tail-water curve, Figure 5.

Since friction losses are relatively higher in the model than in the prototype, computations were made, using Manning's formula, to determine the length of tunnel required downstream from the gate chamber to give velocities in the model comparable to those in the prototype. As a result of these computations the model tunnel was shortened 28 percent to give velocities at the origin of the trajectory curve corresponding to the computed velocities in the prototype.

The 1:20 model was used to study the flow conditions in the tunnel and the performance of the stilling basin.

The 1:9.75 Model

The 1:9.75 model was built to study the flow characteristics in the downstream gate frame. Therefore, only the gate and downstream gate frame were made geometrically similar to the prototype. The model was composed of a 20-foot length of 6-inch conduit terminating in a short transition section to which the 4- by 4-inch slide gate was fastened, Figure 6. A flow straightener was placed in the upstream end of the conduit to provide uniform flow into the slide gate. The slide gate, previously built for other model studies, was modified to conform to the design proposed for Keyhole outlet works. The roof of the downstream gate frame was fitted with piezometers and constructed of transparent plastic to permit observation of the flow as the jet left the gate leaf.

THE INVESTIGATION

The investigation was concerned primarily with the distribution of flow in the tunnel and the performance of the stilling basin when one or both slide gates were discharging 750 and 1,500 second-feet, respectively, at maximum reservoir elevation 4128.1. These flows created the most severe conditions both in the tunnel and the stilling basin. Studies were also made at discharges of 450 second-feet with one gate open and 900 second-feet with both gates open at normal reservoir elevation 4070. In addition, the recommended design was studied with the slide gates partially closed. Thus, a wide range of discharge and operating conditions were studied to make certain the outlet works functioned as intended.

In the preliminary design, the slide gates were 3 feet 3 inches square and the tunnel was 8 feet 9 inches wide and 7 feet 7-1/2 inches high. After the 1:20 model was built, the slide gate design was modified by adding small deflectors upstream from the gate slots. This modification was the result of model studies made on the high-pressure slide gate for Cedar Bluff outlet works.* The installation of gate slot deflectors reduced the coefficient of discharge from 0.95 to 0.84, thus necessitating larger gates to discharge the design flow. Therefore, the size of the slide gates was increased to 3 feet 6 inches square and the tunnel dimensions were changed to 9 feet 6 inches wide and 8 feet 3 inches high. The model gates and tunnel were not changed to conform to these new dimensions, because the studies were essentially completed and it was felt that the relatively small change in size would have little effect on the flow characteristics in the model or in the prototype.

Slide Gate Studies

The 1:20 model. The preliminary design, Figures 3 and 4, was initially tested using a discharge of 1,500 second-feet at maximum reservoir elevation 4128.1 with both slide gates fully open. Under these conditions a high fin of water which extended to the crown of the tunnel was formed in the center of the tunnel below the gate chamber where the two jets came together, Figure 7a. When the gates were less than 95 percent open, the fin was reduced substantially. It was found that for gate positions of approximately 95- to 100-percent open, the jet adhered to the sloping top of the downstream gate frames and the high fin, described above, became more prominent.

Of primary concern, however, was the fact that the downstream gate frame acted as a draft tube within the above range of discharges and a high coefficient of discharge was noted, indicating the presence of subatmospheric pressures.

*Hydraulic Laboratory Report No. Hyd-245, "Hydraulic Model Studies of Cedar Bluff Outlet Works."

Since the 1:20 model of the outlet works was comparatively small for a reliable study of the flow characteristics in the gate, a larger model of the slide gate was constructed on a scale of 1:9.75.

The 1:9.75 model. Tests on this model disclosed a flow pattern similar to that obtained on the smaller 1:20 model, but within a different range of gate openings. When the slide gate was exactly 100-percent open, the upper nappe of the jet was clear of the downstream frame and apparently fully aerated back to the gate leaf, Figure 8a. However, when the gate leaf was raised to a position 100.6-percent open, the jet clung to the roof of the downstream frame as in the 1:20 model, Figure 8b. The flow pattern persisted throughout the entire range of heads on the gate. When the gate was 100.6-percent open and at maximum head, the piezometers in the roof of the downstream frame indicated a maximum subatmospheric pressure of minus 5.2 feet of water at a point 5.5 inches downstream from the gate leaf. The pressure increased to atmospheric from this point downstream to the end of the frame.

When the gate was raised further to a position approximately 101-percent open, the jet again flowed clear and no subatmospheric pressures were noted, Figure 8c. Although the lowest pressure noted in the gate frame is above the cavitation range, it can be assumed that still lower pressures may have existed between the gate leaf and the point of lowest observed pressure. This assumption is based on the fact that the pressures progressively increased to atmospheric at the downstream end of the gate frame.

From these tests it is concluded that the flow in the gate structure, described above, will be satisfactory if the gate is operated less than 98-percent open.

Tunnel Studies--1:20 Model

Preliminary wall. As stated above under Slide Gate Studies--1:20 Model, a high fin of water formed in the center of the tunnel below the gate chamber. Although this fin was reduced materially when the gates were lowered to 95-percent open, there still remained a small fin of water and some splash at the end of the splitter wall immediately downstream from the gate chamber where the jets came together.

When one gate was closed, the center fin was eliminated, but on leaving the end of the splitter wall the jet spread to the opposite side of the tunnel, causing the flow to swing to alternate sides of the tunnel as it passed downstream, Figure 7c. This unsymmetrical flow continued into the stilling basin where an uneven jump formed, Figure 7d.

These flow conditions also persisted at lower reservoir elevations but their prominence diminished as the head water was lowered. Although the disturbance at the end of the splitter wall had little effect on the stilling basin action, steps were taken to reduce the tendency of the jet to swing when one gate was closed.

Wall No. 2. The splitter wall between the gates was lengthened to 22 feet 9 inches, tapered from 2 feet 3 inches wide at the gate to 8 inches at the downstream end, and sloped from 3 feet 8 inches in height at the gate to 8 inches high, Figure 9b. This arrangement almost eliminated the center fin when both gates were operating. However, when one gate was closed, the jet crossed over the sloping top of the splitter wall and caused more disturbance in the tunnel than in the preliminary design.

Wall No. 3. Next, a splitter wall similar to the one described above but with a level top, Figure 9c, was tested. This wall gave a much better distribution of flow with only one gate open. The tendency for the jet to swing from side to side of the tunnel was still present but much less pronounced. When both gates were open, a small fin still formed at the end of the splitter wall but the splash was reduced.

Wall No. 4. To determine whether a shorter wall would be satisfactory, a splitter wall 14 feet long was installed in the model, Figure 9d. The shorter wall made the center fin more pronounced when two gates were operating and, with one gate closed, the flow appeared less symmetrical in the tunnel. It was decided to use the 22-foot 9-inch wall, Wall No. 3, shown in Figure 9c and develop other means to improve the unsymmetrical flow in the tunnel when one gate was closed.

Stilling Basin Studies

Preliminary design. As shown in Figure 7d and described under Tunnel Studies--1:20 Model on page 5, the unsymmetrical flow persisted throughout the length of the tunnel and caused a flow concentration on one side of the stilling basin. When both gates were open, the flow concentrated in the center of the stilling basin. Although the longer splitter wall helped to distribute the flow more evenly as it entered the stilling basin, it was felt the flow distribution could be further improved.

Revision No. 1. A hump, 2 feet 6 inches in height, was placed on the tunnel invert near the downstream end of the tunnel, Figure 10a. This change was ineffective in improving the flow distribution. The flow still concentrated in the center of the basin when both gates were operating and, when one gate was closed, most of the flow shifted to one side.

Revision No. 2. The previous revision indicated a still larger hump might distribute the flow more evenly as it entered the stilling basin. A hump of dimensions and shape similar to that in use at Caballo Dam outlet works** was installed in the model, Figures 10b and 11b. In general, the flow conditions were worse with the Caballo hump installed. In addition to the unsymmetrical flow, the jet failed to penetrate the stilling pool and skipped along the pool surface, Figure 11c.

From these tests, it became apparent that the unsymmetrical flow should be corrected in the tunnel rather than at the stilling basin entrance.

**Hydraulic Laboratory Report No. Hyd-72, "Hydraulic Model Studies for the Design of Caballo Dam Outlet Works and Spillway."

Revision No. 3. Revision No. 3 consisted of placing a ridge, triangular in cross section and 20 inches in height along the center line, on the invert of the tunnel from Station 10+51 to the tunnel portal, Figure 10c. It was hoped the ridge would serve to partially divide the flow and force more to the outside edges of the stilling basin.

The ridge helped materially in forcing more flow to the outside of the stilling pool when both gates were operating. With one gate closed, the flow distribution in the stilling basin could be made satisfactory at a given head and discharge. However, when the head or discharge was increased or lowered, the frequency of the jet swing from the tunnel sides was changed and the hydraulic jump in the stilling basin again became unsymmetrical.

In an attempt to make the flow uniform at all heads and discharges, the 40-foot length of ridge was moved to a position immediately downstream from the gate chamber. This arrangement gave fair flow conditions over a wider range of discharges, but in the near maximum discharge range, the flow still tended to concentrate on one side of the stilling pool.

Revision No. 4. The studies made with the previous arrangement indicated that the ridge should extend over a greater length of the tunnel if it were to be effective in distributing the flow when one gate was closed. Therefore, a ridge 7-1/2 inches in height and extending from the gate chamber to the origin of the trajectory curve was installed in the model, Figure 10d. This scheme improved the distribution of flow when one gate was closed. The flow was comparatively uniform at the downstream end of the tunnel when either one or both gates were discharging. Upon leaving the tunnel, however, the water tended to concentrate in the center of the stilling pool. This was especially noticeable when the gate (or gates) were releasing the maximum discharge.

Revision No. 5. Since the flow distribution at the downstream end of the tunnel was satisfactory, it was believed that the concentration of flow in the center of the stilling basin could be improved by lengthening the horizontal section between the end of the tunnel and the origin of the trajectory curve. Thus, the angle of divergence of the training walls would be less and the change from the 8-foot 9-inch width at the tunnel to the 25-foot stilling basin would be more gradual. Revision No. 5 consisted of lengthening the horizontal section from 20 to 35 feet, Figure 10d. This change gave satisfactory flow distribution in the stilling basin at all discharges. The hydraulic jump was very stable and the full basin width was utilized in dissipating the jet energy, Figure 12.

The Recommended Design

The recommended design, evolved from the preceding studies, is shown on Figures 13 and 26. This design includes splitter Wall No. 3 described on page 6 and stilling basin Revision No. 5 shown on Figure 10d. Figures 12, and 14 to 19, inclusive, show the operation of the model for one and two gates open with reservoir elevation 4070 and also the flow conditions with one gate 25-, 50-, and 75-percent open and the headwater at maximum elevation 4128.1.

For the purpose of determining the height of training walls required and to evaluate the flow distribution in the stilling basin, water-surface profiles were measured along the center line and each edge of the stilling basin, Figure 20. Profiles were recorded with one and two gates operating when the reservoir level was at maximum elevation 4128.1. These profiles indicate that the distribution of flow was satisfactory both upstream from the origin of the trajectory curve and also in the stilling basin itself.

The results of scour tests made on the recommended design are shown in Figure 21. The scour indicated in Figures 21b and 21c resulted after operating the model for a period of time equivalent to 2.25 hours' prototype at discharges of 750 and 1,500 second-feet with one and two gates, respectively, open. The maximum scour under these conditions occurred immediately downstream from the end sill and amounted to 0.7 foot in both cases.

Three regions of the outlet works were investigated for low pressures. Four piezometers were installed on one side of the bellmouth entrance to the gate chamber. The piezometer locations and the pressures recorded at each point are shown in Figure 22. Pressures were observed for a range of discharges varying from 300 second-feet with one gate closed to 1,500 second-feet with both gates operating. The pressures were all above atmospheric within the range of head and discharges tested. Thus, no adverse pressures are anticipated in the bellmouth entrances to the gate chamber.

Two piezometers were installed at the high point of the ridge 41 and 80 feet downstream from the gate leaf, Figure 23. These piezometers were used to determine whether adverse pressures existed on the tunnel invert where the jet crossed over the high point of the ridge. Pressures measured in this region were all above atmospheric for the range of discharges tested, indicating that the reduction in pressure was insignificant due to the water passing over the ridge.

Eight piezometers were placed in the stilling basin at 5-foot intervals along the center line of the trajectory curve. Pressures were recorded with the reservoir at elevation 4070 and at maximum elevation 4128.1 when two gates were operating and also at partial openings when one gate was closed. Results of these tests are shown on Figure 24. The lowest pressure, 0.1 foot (prototype) below atmospheric, was recorded at Piezometer No. 3 when both gates were discharging 1,500 second-feet at maximum reservoir elevation. Therefore, the trajectory curve is adequately safe against cavitation.

Head Loss in Gate Chamber

As an aid in determining the size of slide gates and tunnel required to pass the design flow, the loss of head in the gate chamber was measured in the 1:20 model. The losses were determined from two piezometer rings--one located in the tunnel upstream from the gate chamber at Station 7+25.33 (Section 1) and the other in the reduced section of the gate chamber upstream from the slide gates at Station 7+45.83 (Section 2), Figure 25. The curve shown in this figure represents the total loss of head between Sections 1 and 2 for different discharges with both gates fully open. Since the model was relatively small and was built for purposes other than determining head losses in the gate chamber, these data should be used with caution.

Method of Prototype Operation

It is recommended that, whenever possible, water be released through the outlet works by equally opening both gates. Although the stilling basin performed satisfactorily when one gate was discharging, the model clearly indicated that, for any discharge, the flow was more evenly distributed in the tunnel and a more uniform jump formed in the stilling basin when both gates were discharging an equal amount of water.

The models also indicated that subatmospheric pressures may occur in the roof of the downstream gate frame at gate openings above 98 percent. Therefore, except in emergencies, the slide gates should be operated at openings of less than 98 percent.

Interior - Reclamation - Denver, Colo.

FIGURE 1
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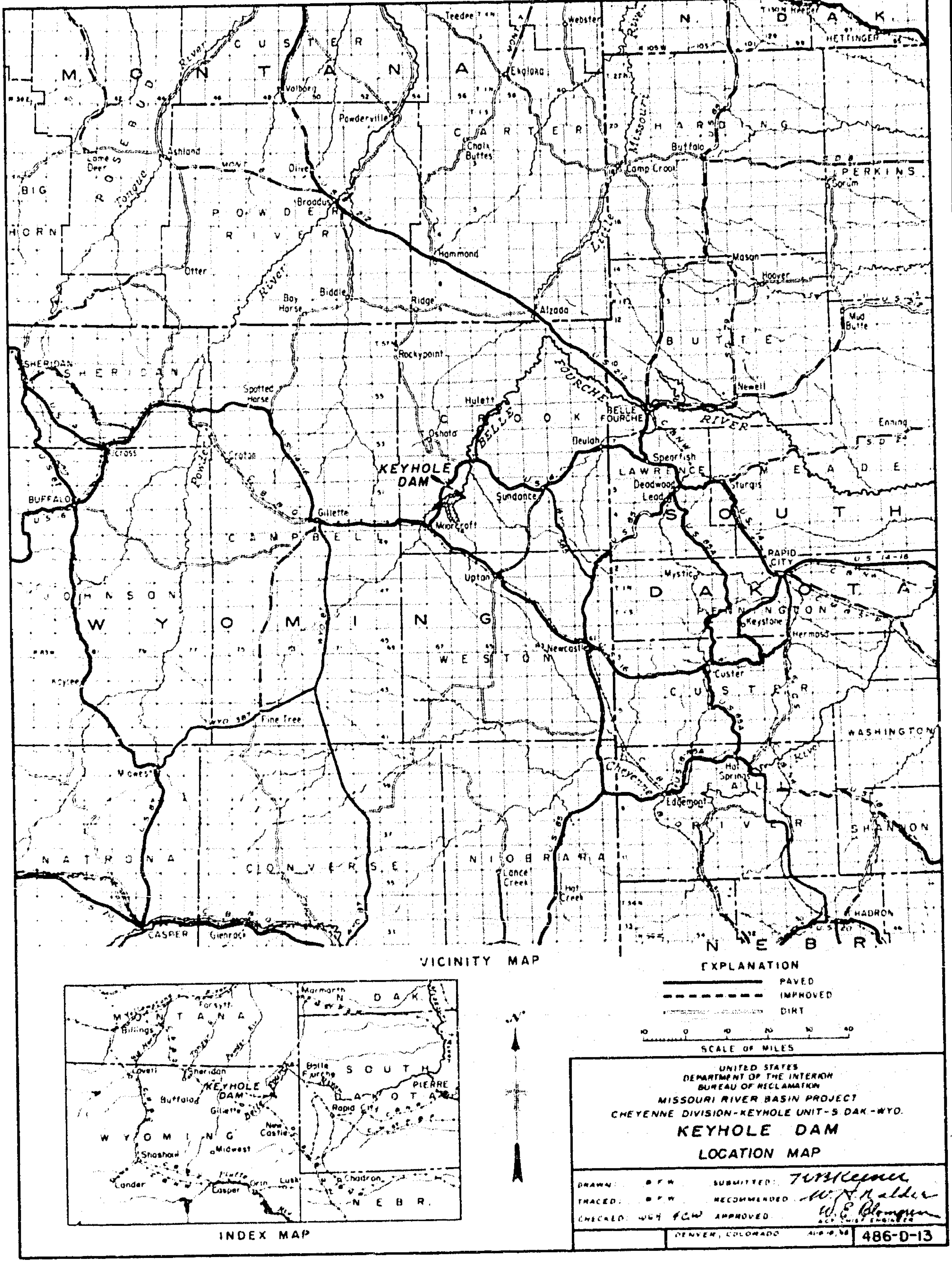

FIGURE 2
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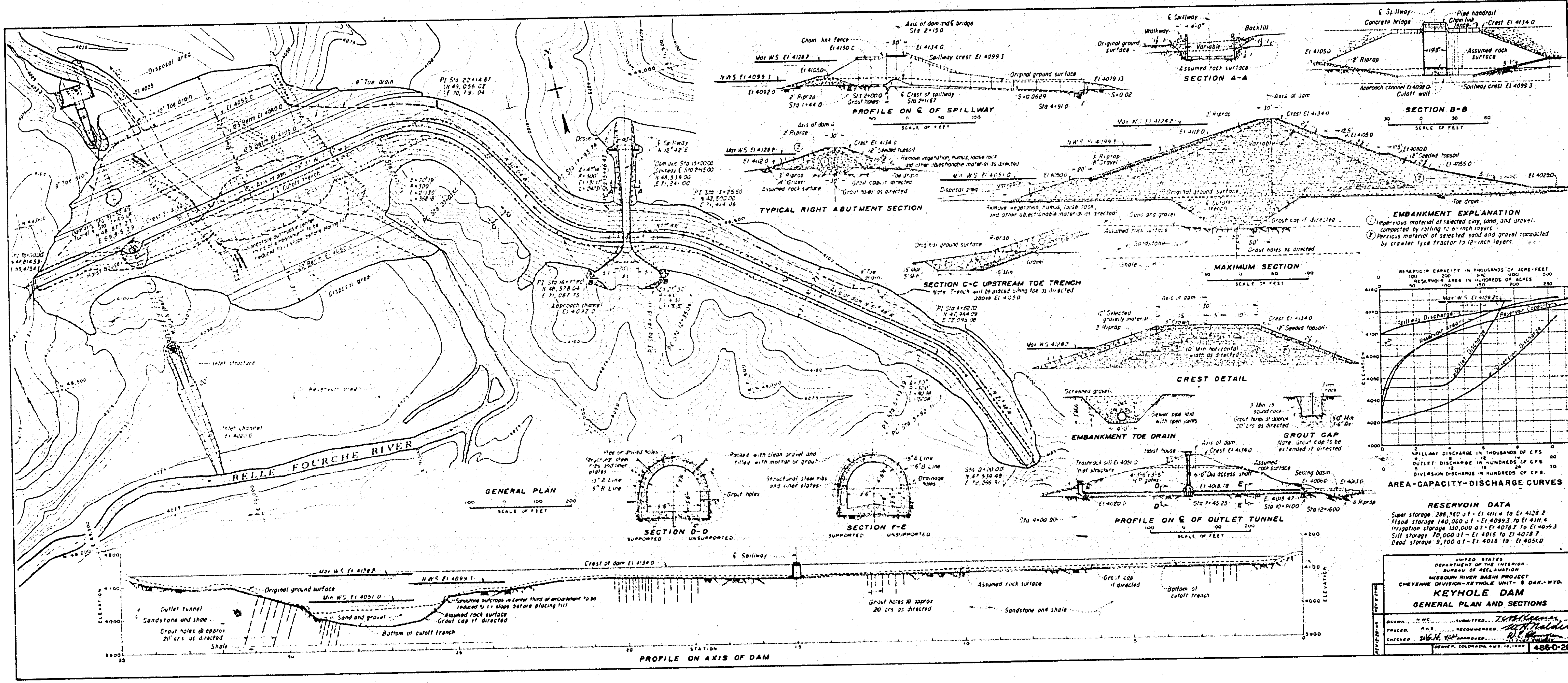
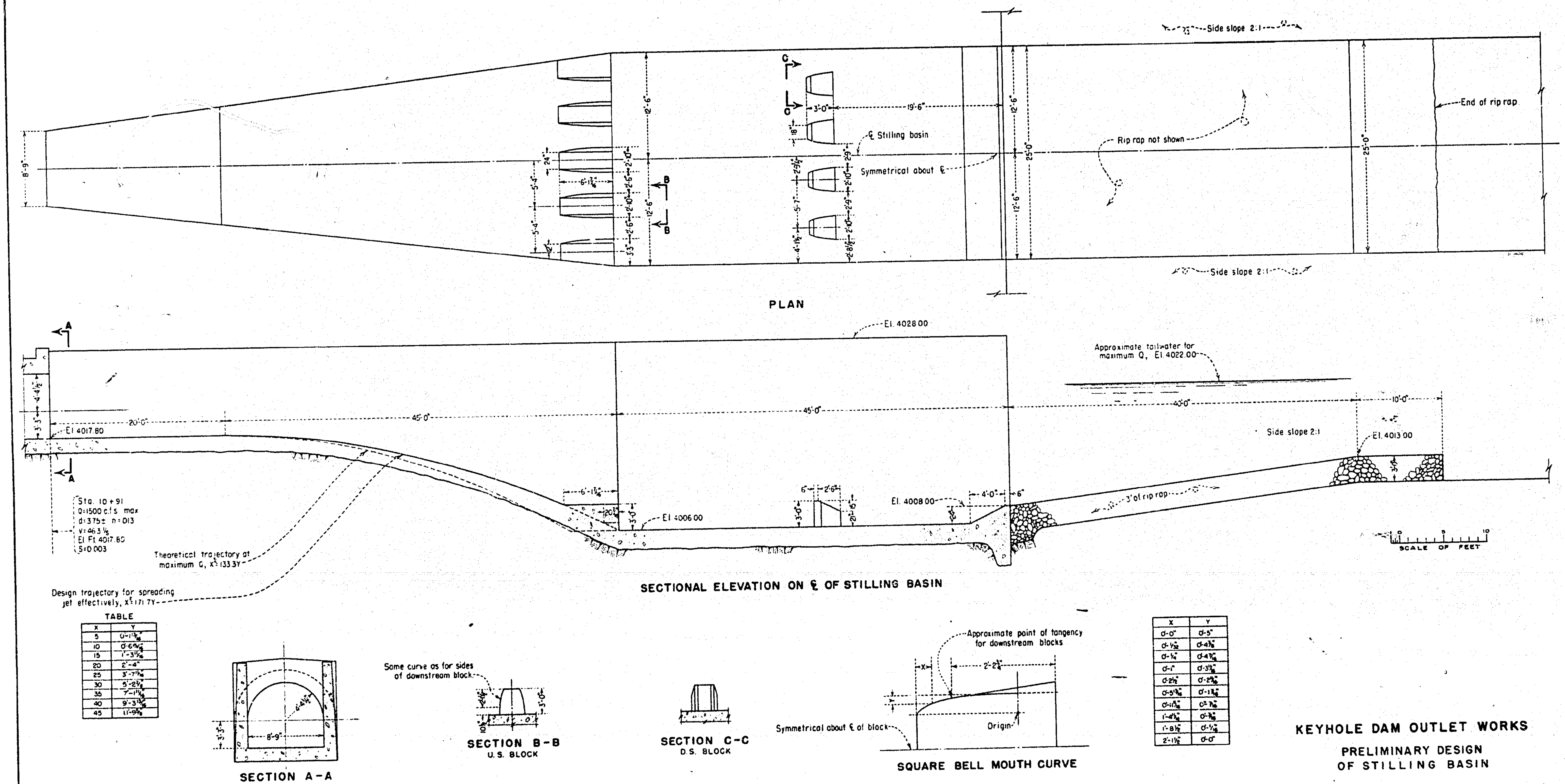




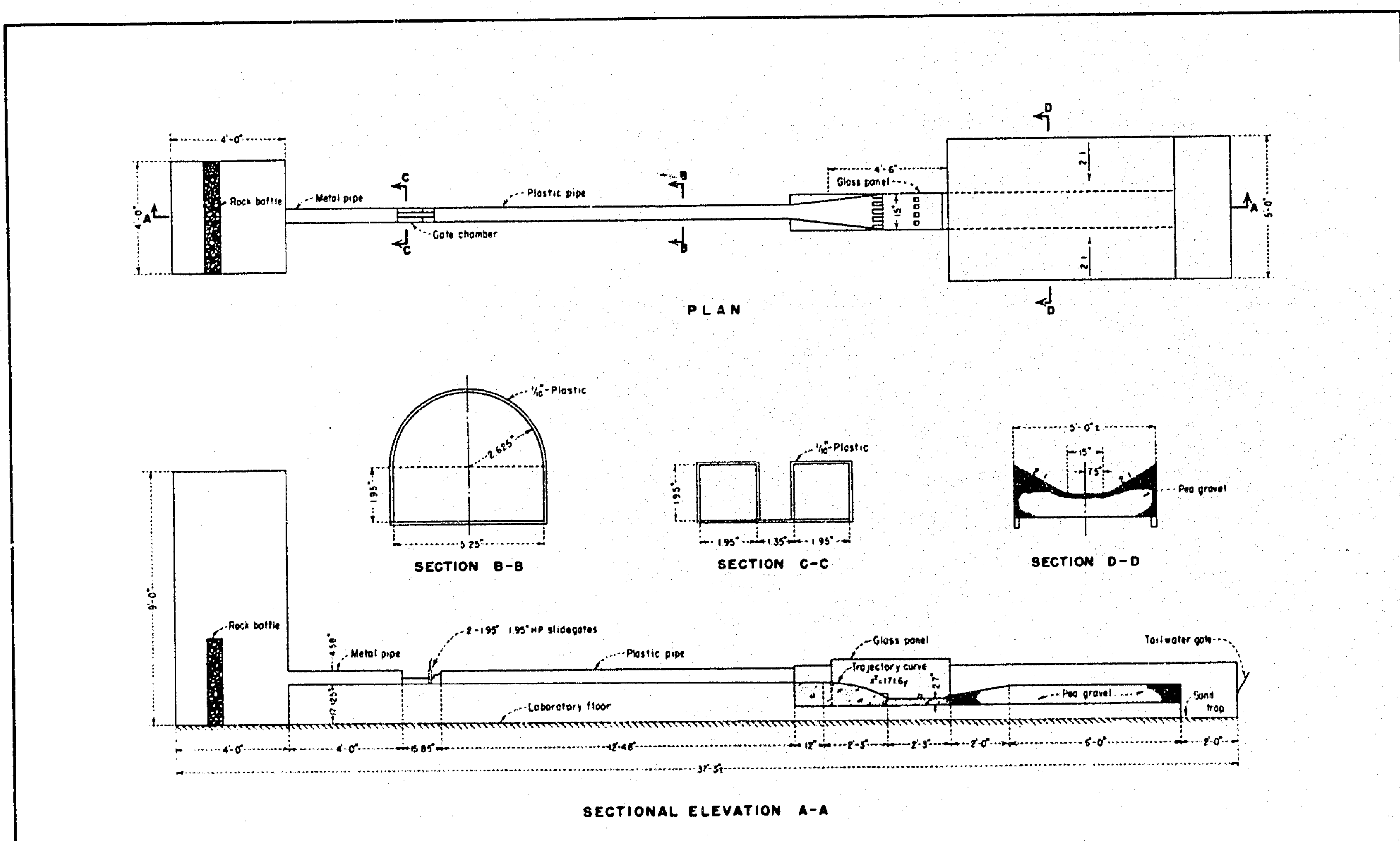
TABLE

X	Y
5	0'-1 13/16"
10	0'-6 15/16"
15	1'-3 11/16"
20	2'-4"
25	3'-7 11/16"
30	5'-2 7/8"
35	7'-1 11/16"
40	9'-3 13/16"
45	11'-9 5/8"

X	Y
0'-0"	0'-5"
0'-1/32"	0'-4 7/8"
0'-1/4"	0'-4 9/16"
0'-1"	0'-3 13/16"
0'-2 1/2"	0'-2 13/16"
0'-5 13/16"	0'-1 13/16"
0'-11 5/16"	0'-7/16"
1'-4 1/16"	0'-3/16"
1'-8 1/2"	0'-1/16"
2'-1 1/2"	0'-0"

KEYHOLE DAM OUTLET WORKS

PRELIMINARY DESIGN OF STILLING BASIN



KEYHOLE DAM OUTLET WORKS

THE 1:20 MODEL

FIGURE 4
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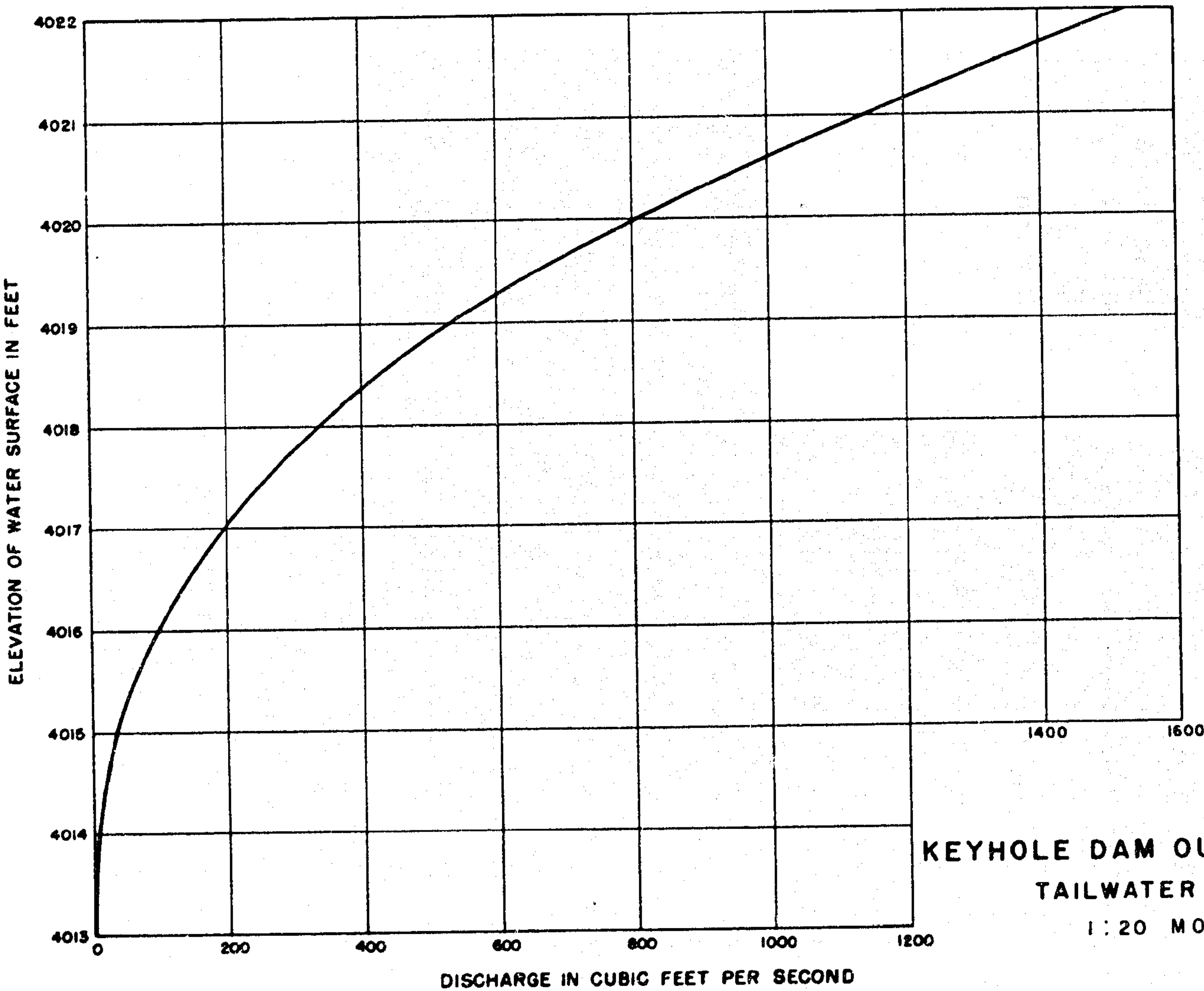

KEYHOLE DAM OUTLET WORKS
TAILWATER CURVE
1:20 MODEL

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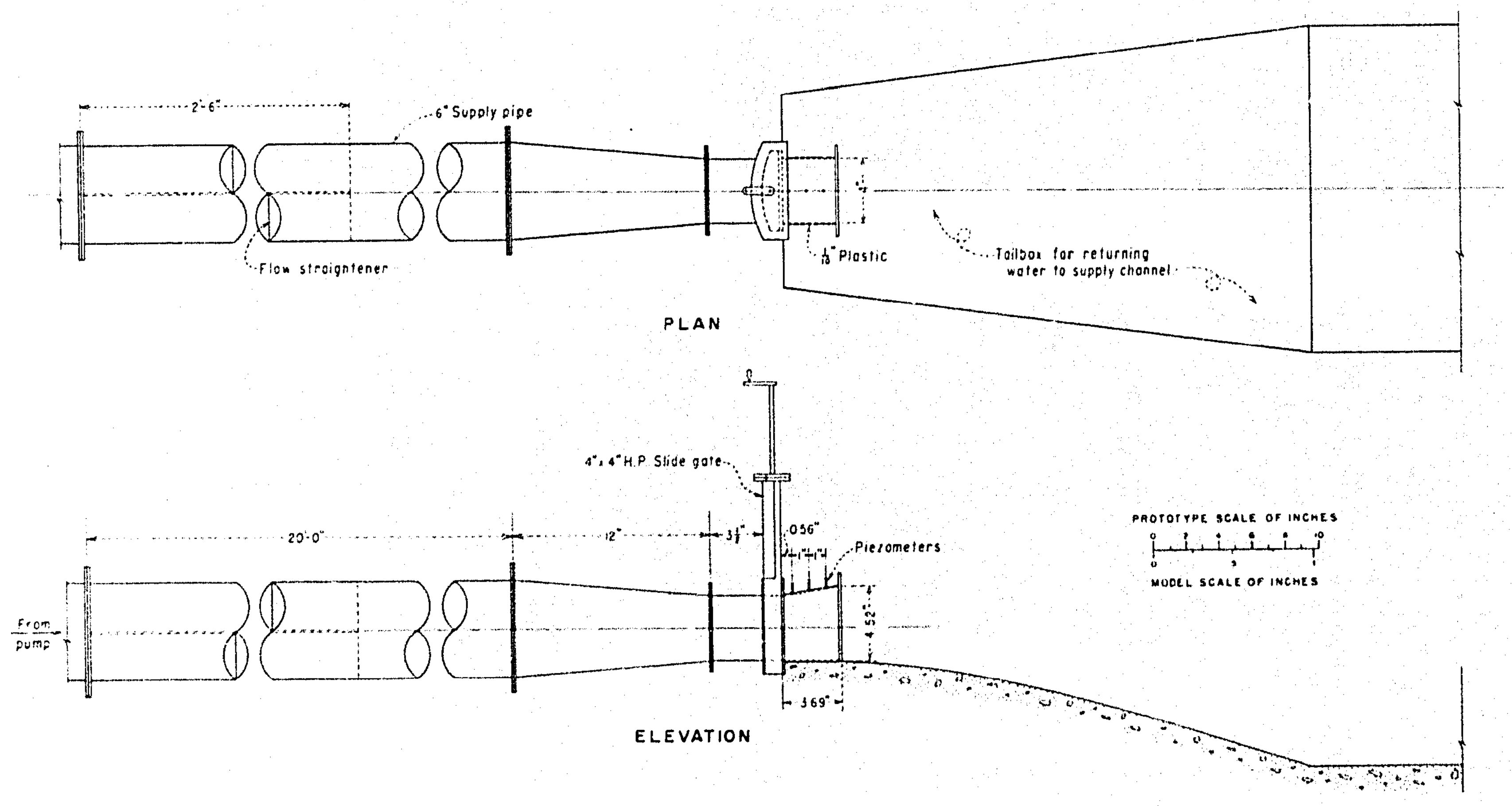

KEYHOLE DAM OUTLET WORKS

THE 1:9.75 MODEL

FIGURE 6
REPORT HYD 336

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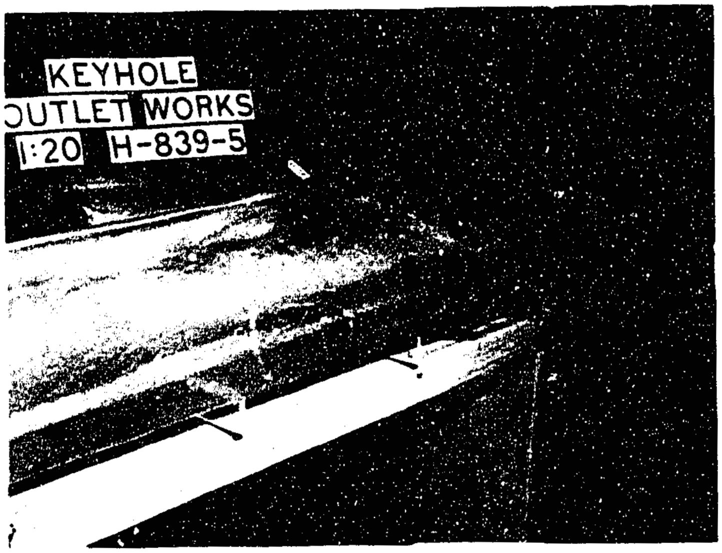
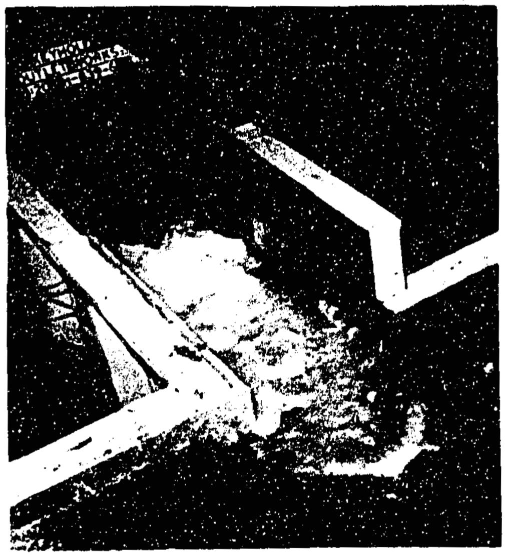
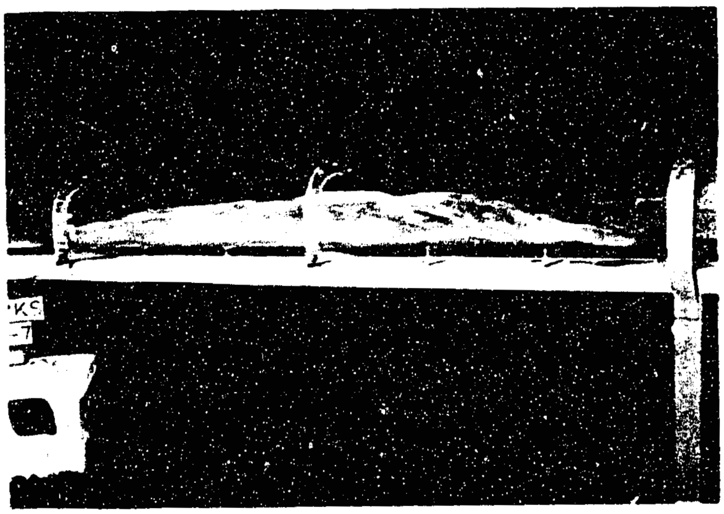


A. Fin downstream from gate chamber

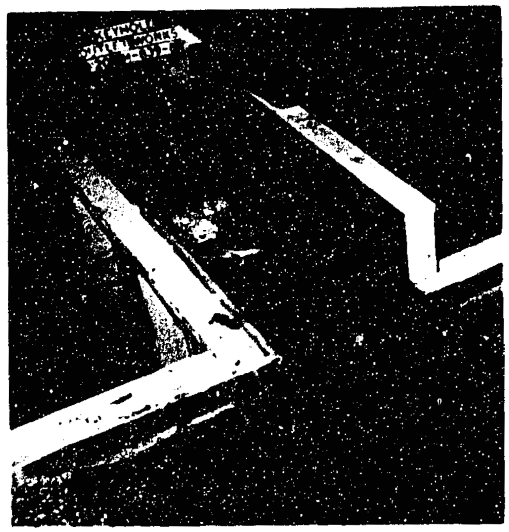


B. Stilling pool operation

Both gates discharging 1500 second-feet
Reservoir Elevation = 4128.1 feet



C. Unsymmetrical flow in tunnel

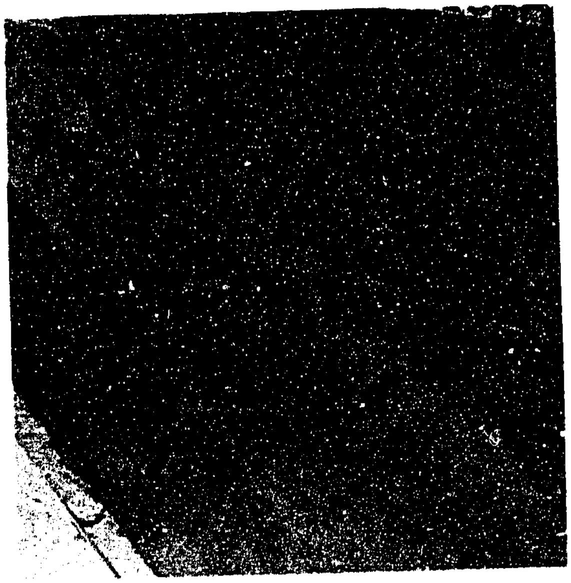


D. Flow concentrated on one side of basin

Right gate discharging 750 second-feet
Reservoir Elevation - 4070 feet

KEYHOLE DAM OUTLET WORKS
Preliminary design
1:20 Model

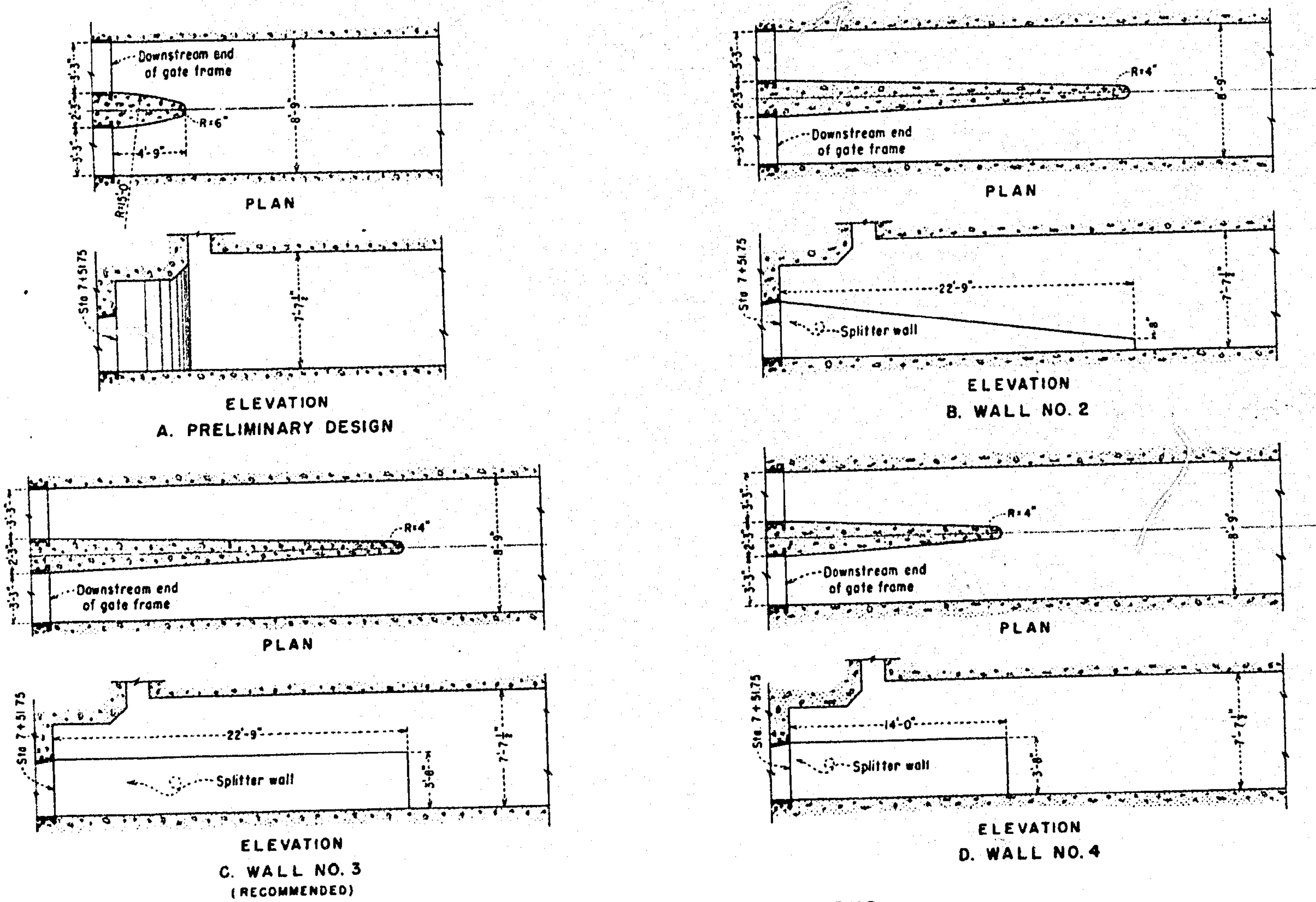
A. Gate 100% open.
Jet free of gate frame



B. Gate 100.6% open.
Jet clings to roof of gate frame.

C. Gate 101% open. Jet
again free of gate frame.

KEYHOLE DAM OUTLET WORKS
Maximum discharge through slide gate
1:9.75 Model



KEYHOLE DAM OUTLET WORKS
VARIOUS SPLITTER WALLS TESTED
1:20 MODEL

FIGURE 9
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FIGURE 10
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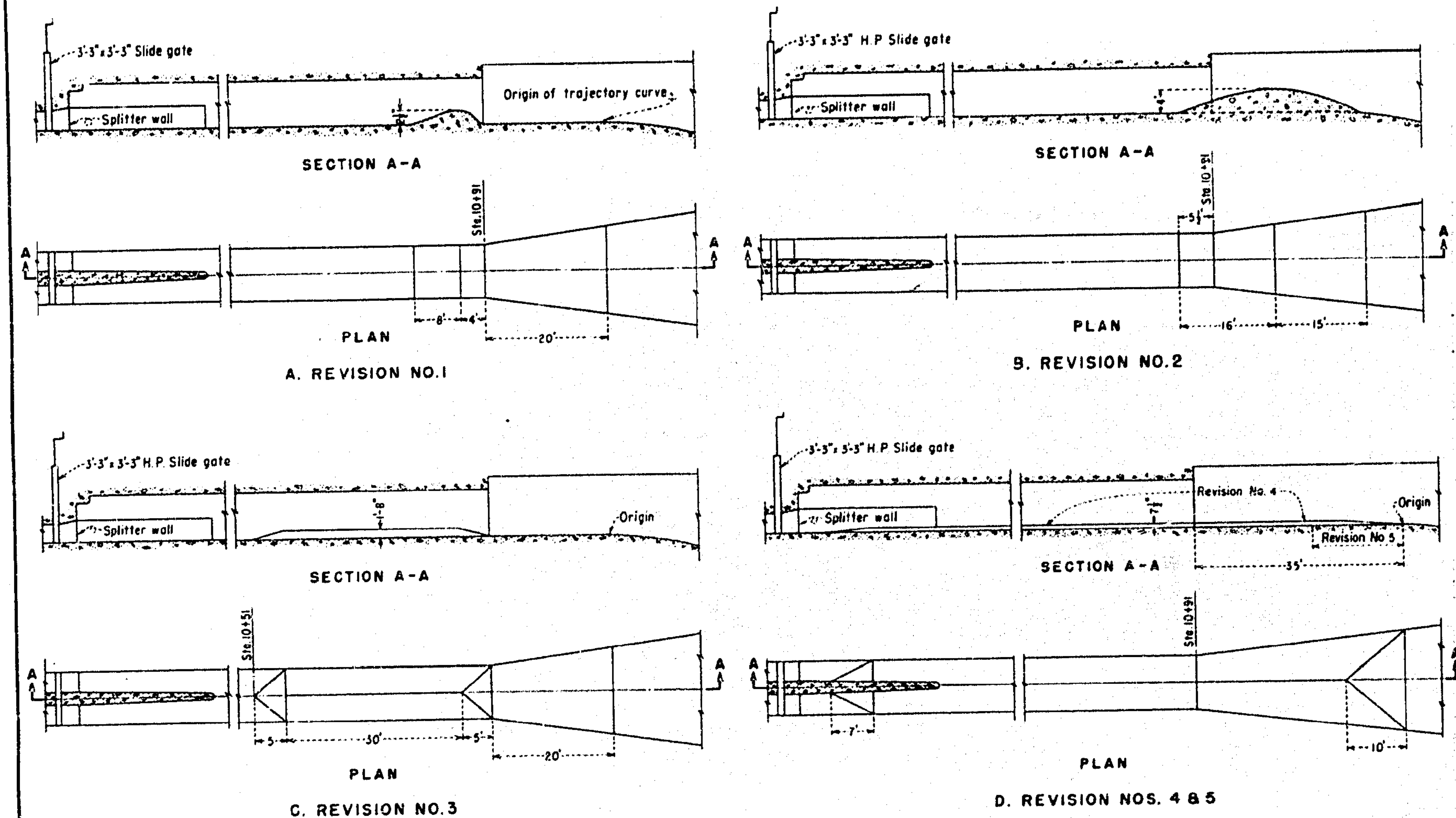

KEYHOLE DAM OUTLET WORKS

REVISIONS TO IMPROVE FLOW DISTRIBUTION IN STILLING BASIN

1:20 MODEL

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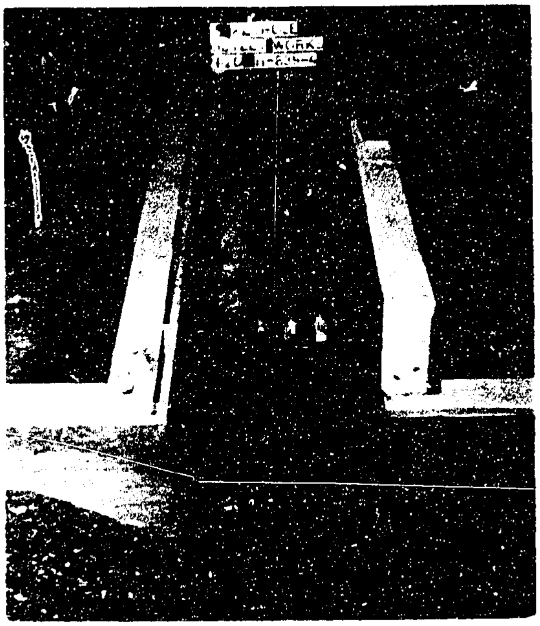
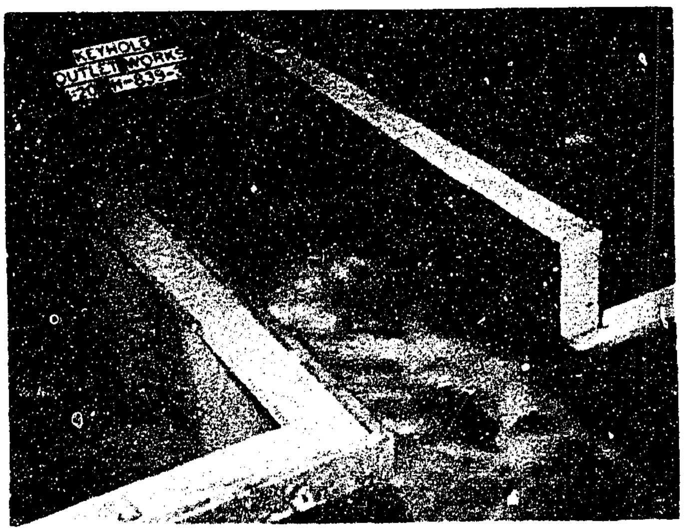


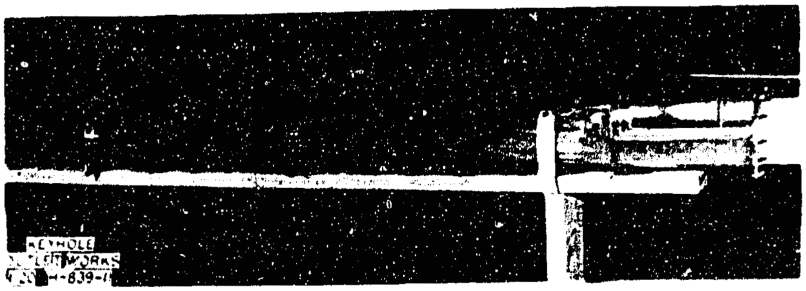
A. Preliminary basin

B. Caballo type hump installed

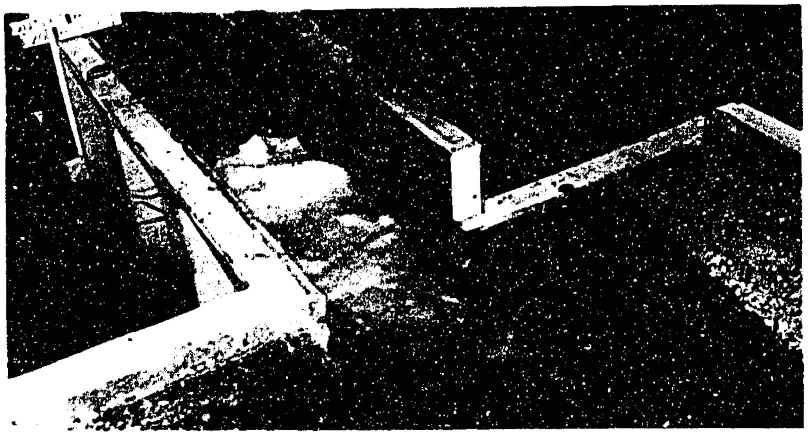


C. Both gates discharging 1500 second-feet with hump installed.

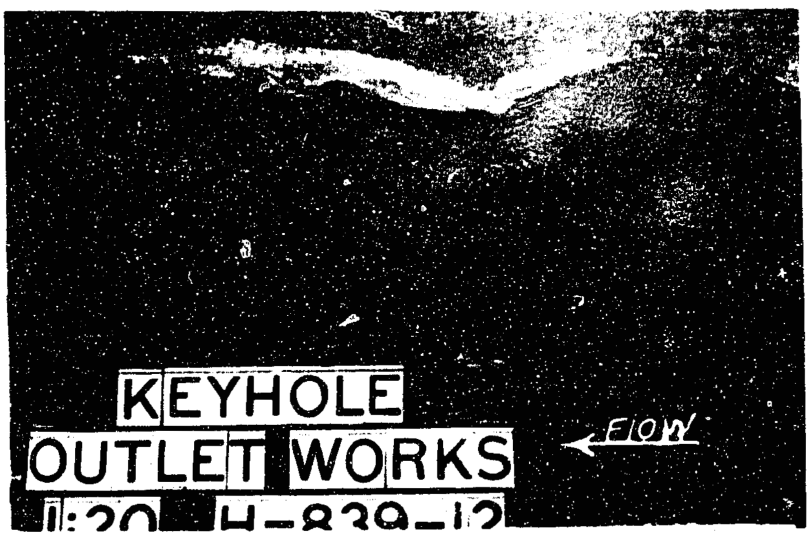
KEYHOLE DAM OUTLET WORKS
Basin operation with Caballo hump installed
1:20 Model



A. Flow in tunnel



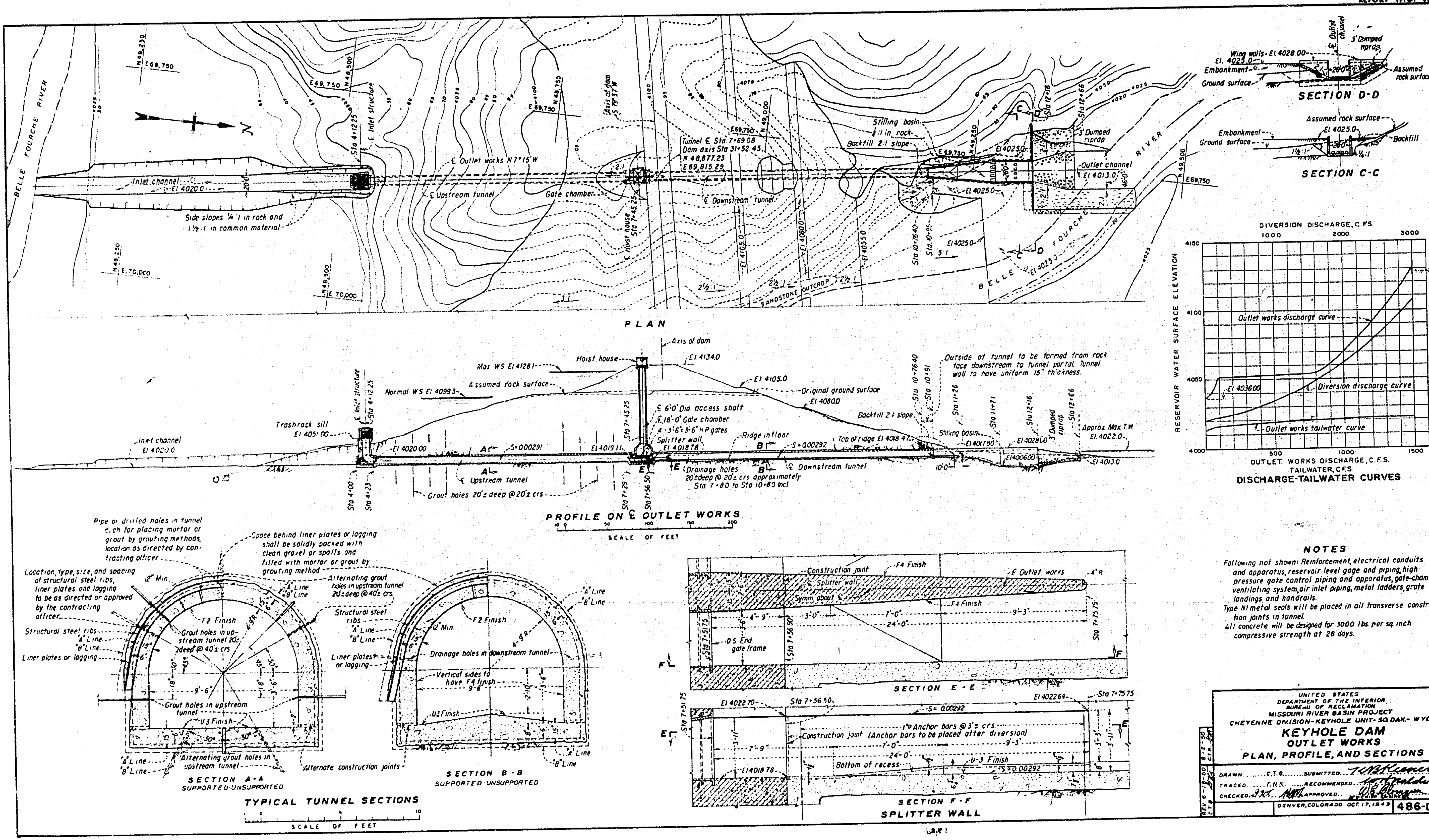
B. Flow distribution in stilling basin



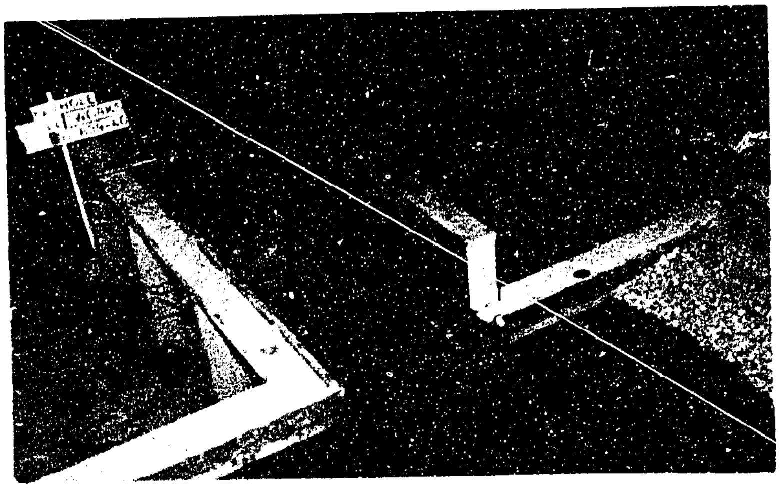
C. Stilling action as seen through window

KEYHOLE DAM OUTLET WORKS
Both gates discharging 1500 cfs.
Reservoir Elevation = 4128.1 feet.
Recommended design - 1:20 Model

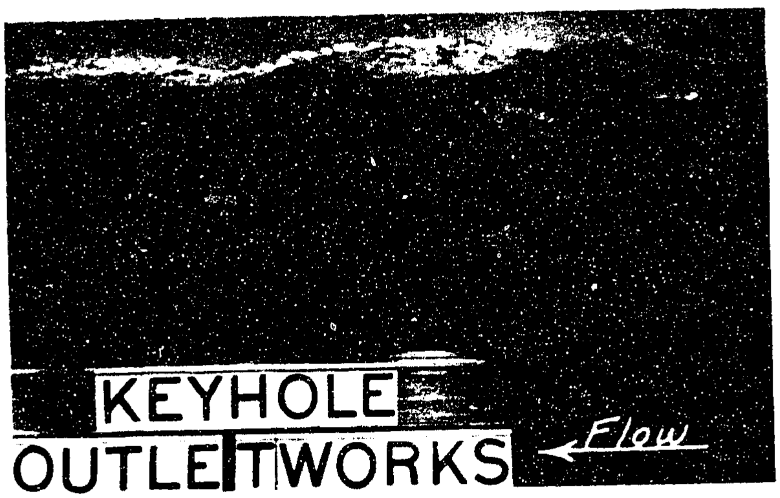
FIGURE 13
REPORT HYD. 339



A. Flow in tunnel

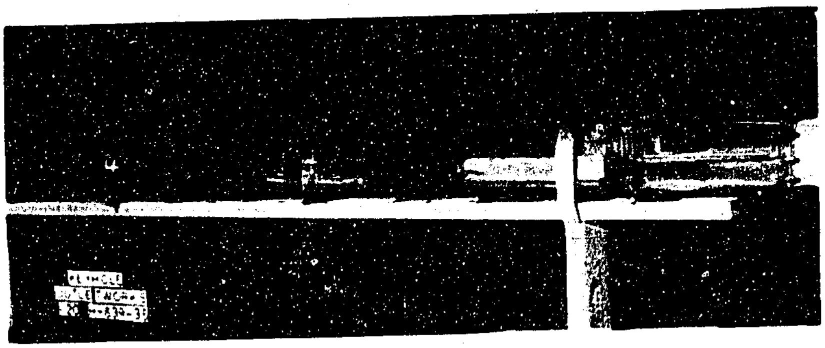


B. Flow distribution in stilling basin

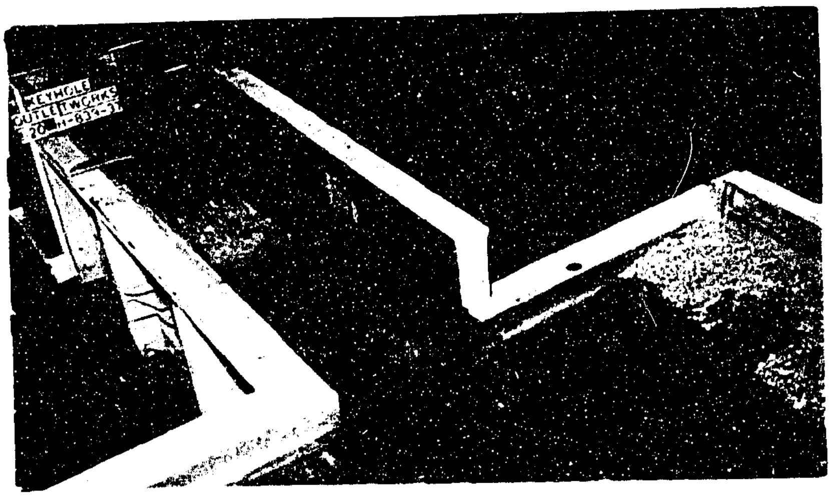


C. Action in stilling pool

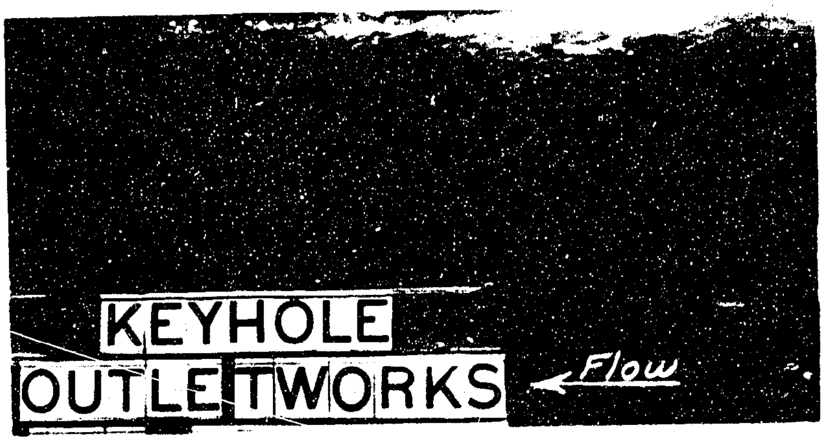
KEYHOLE DAM OUTLET WORKS
Right gate discharging 750 cfs.
Reservoir Elevation = 4128.1 feet
Recommended design - 1:20 Model



A. Flow in tunnel

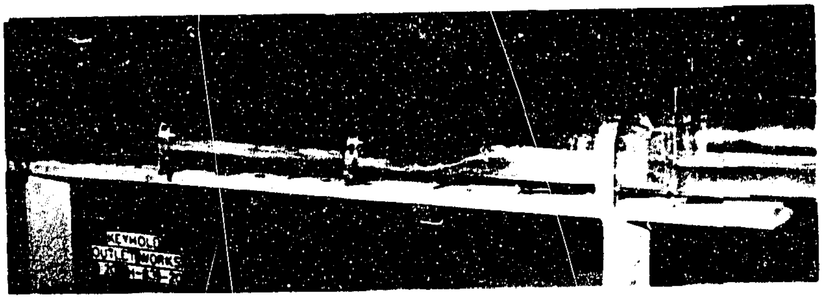


B. Flow distribution in stilling basin

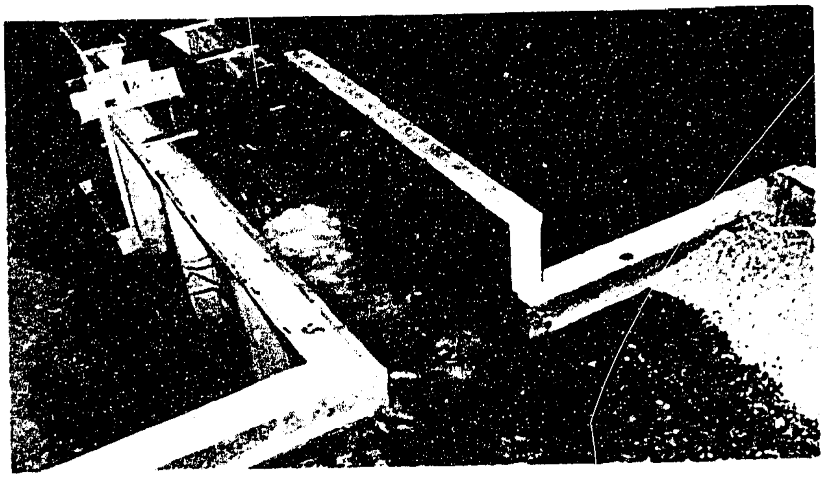


C. Action in stilling pool

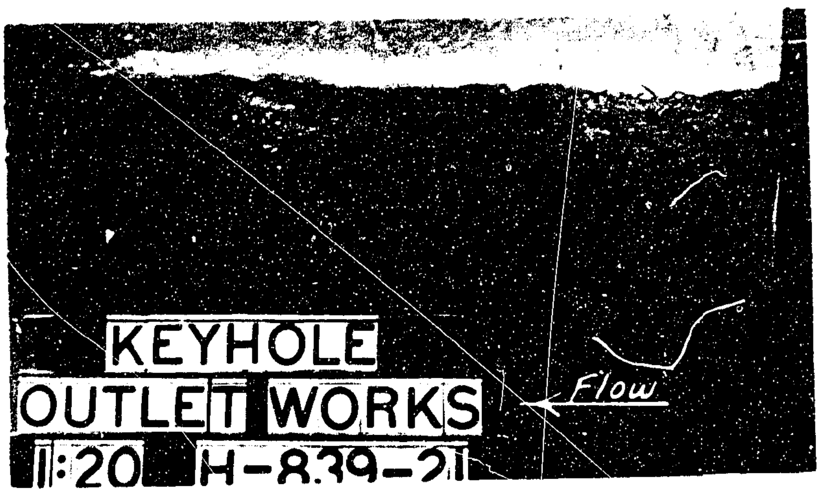
KEYHOLE DAM OUTLET WORKS
Both gates discharging 900 cfs.
Reservoir Elevation = 4070 feet
Recommended design - 1:20 Model



A. Flow in tunnel

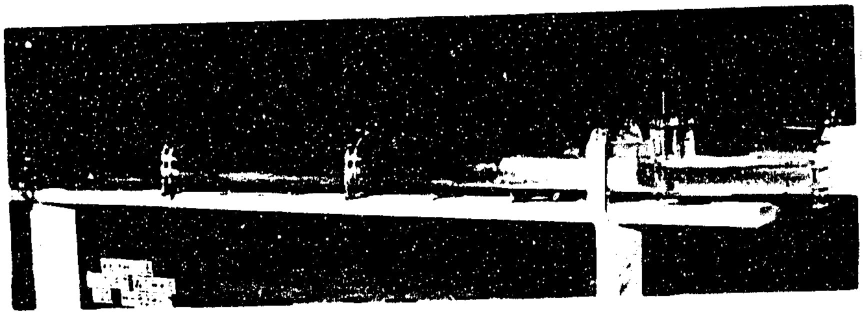


B. Flow distribution in stilling basin

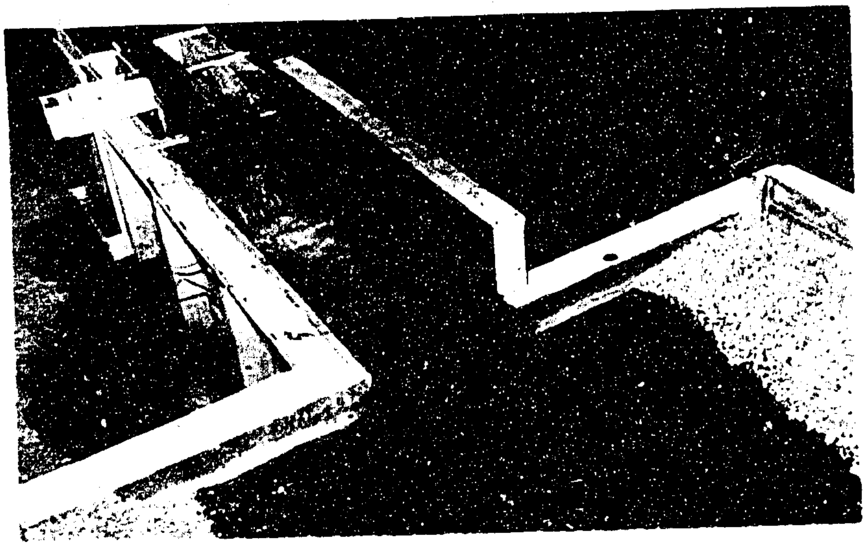


C. Action in stilling pool

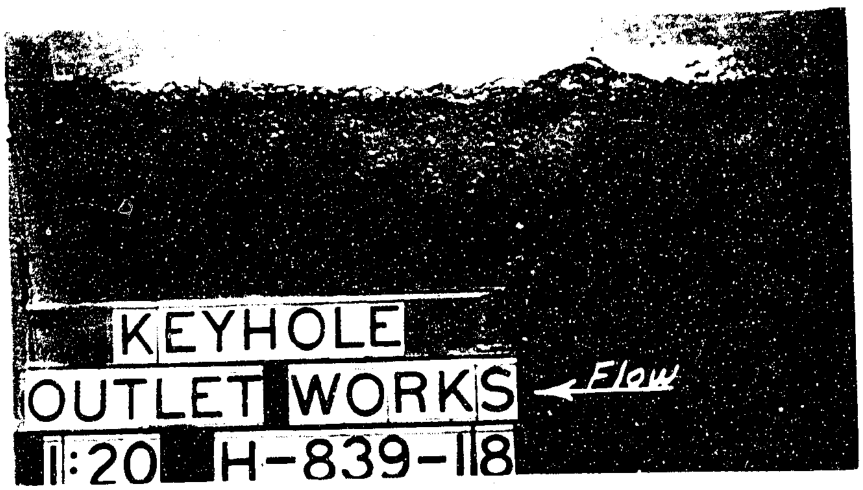
KEYHOLE DAM OUTLET WORKS
Right gate discharging 450 cfs.
Reservoir Elevation = 4070 feet
Recommended design - 1:20 Model



A. Flow in tunnel

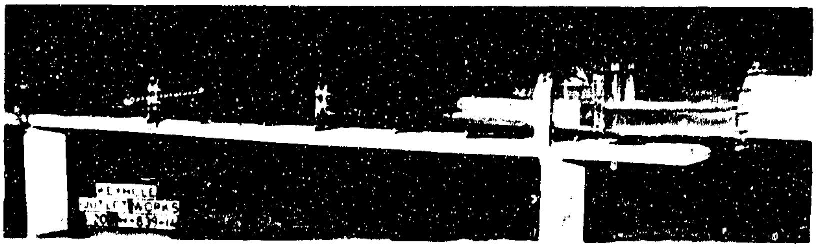


B. Flow distribution in stilling basin

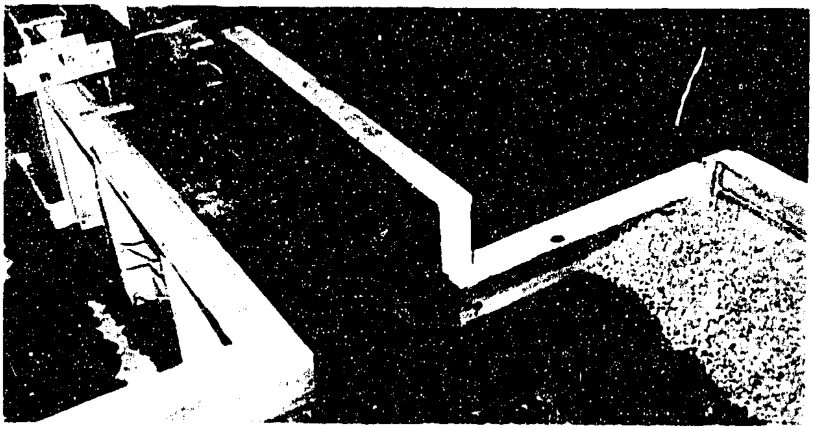


C. Action in stilling pool

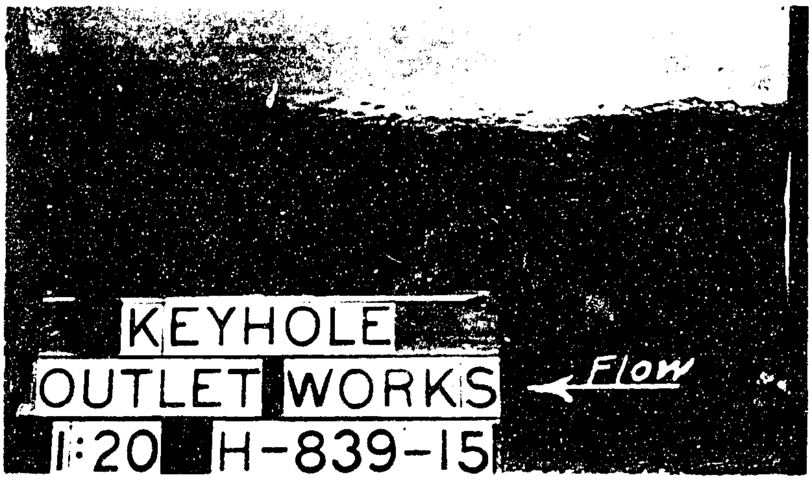
KEYHOLE DAM OUTLET WORKS
Right gate 75% open and discharging 560 cfs.
Reservoir Elevation = 4128.1 feet
Recommended design - 1:20 Model



A. Flow in tunnel

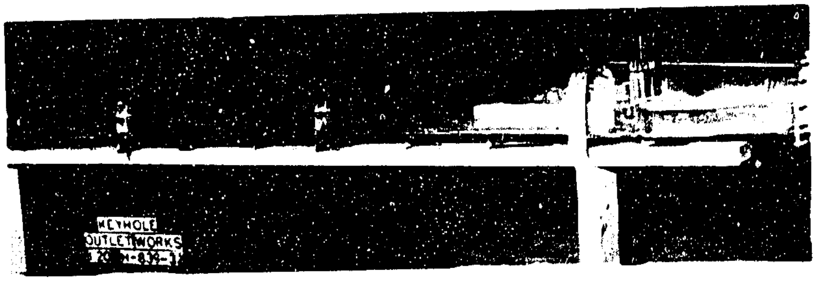


B. Flow distribution in stilling basin

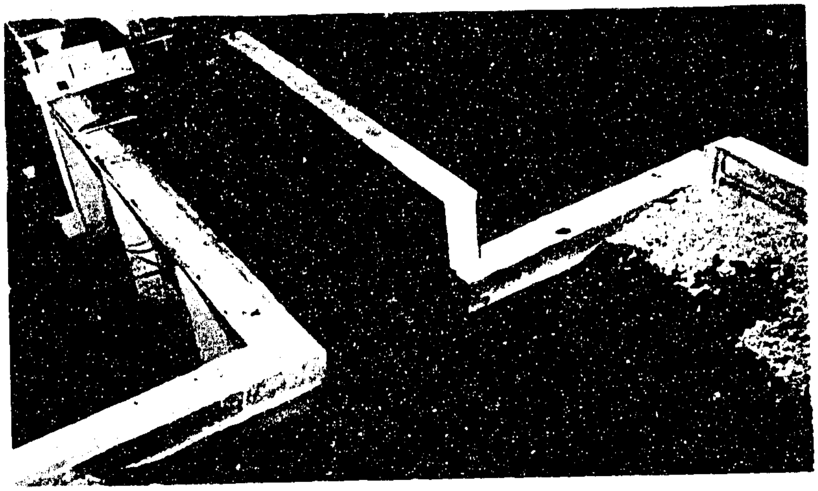


C. Action in stilling pool

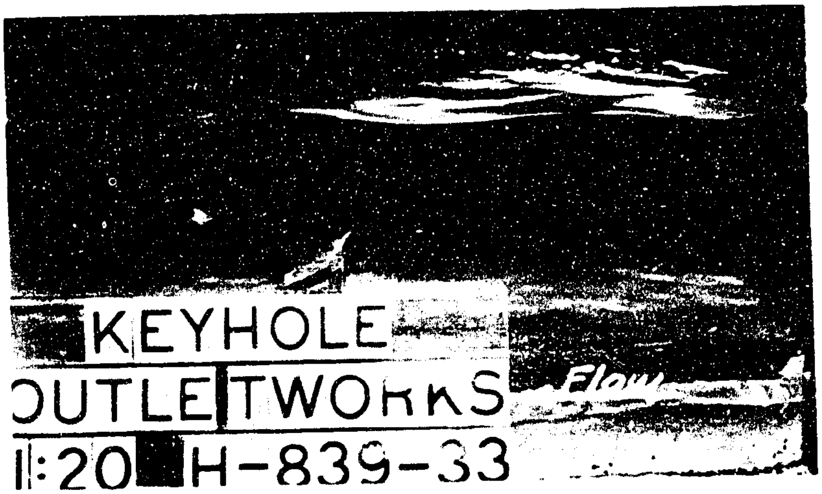
KEYHOLE DAM OUTLET WORKS
Right gate 50% open and discharging 375 cfs.
Reservoir Elevation = 4128.1 feet
Recommended design - 1:20 Model



A. Flow in tunnel

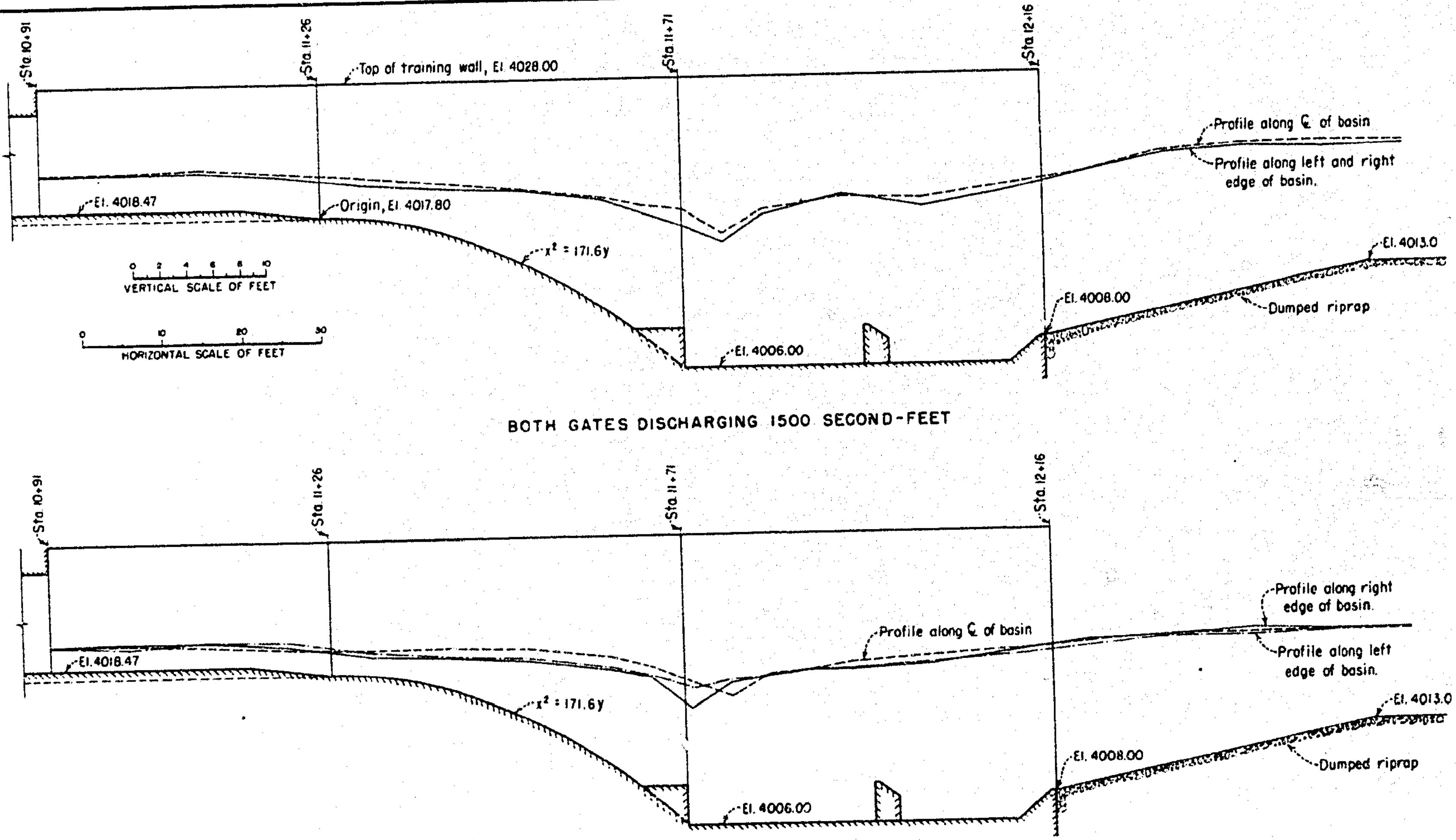


B. Flow distribution in stilling basin



C. Action in stilling pool

KEYHOLE DAM OUTLET WORKS
Right gate 25% open and discharging 190 cfs.
Reservoir Elevation = 4128.1 feet
Recommended design - 1:20 Model



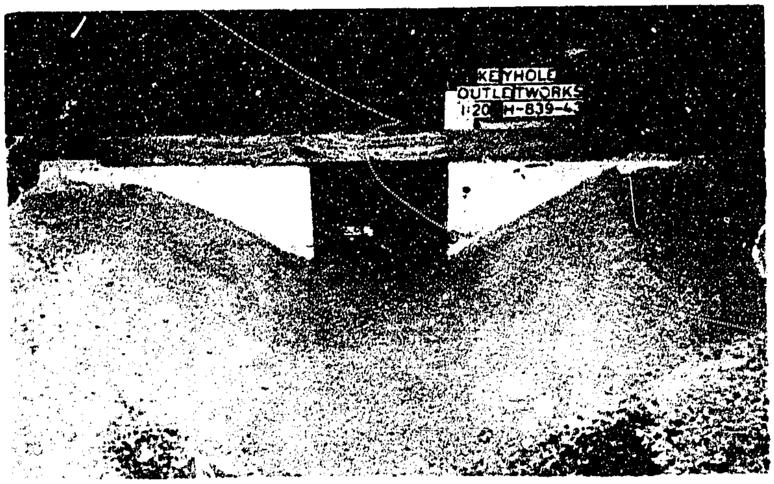
BOTH GATES DISCHARGING 1500 SECOND-FEET

RIGHT GATE DISCHARGING 750 SECOND-FEET

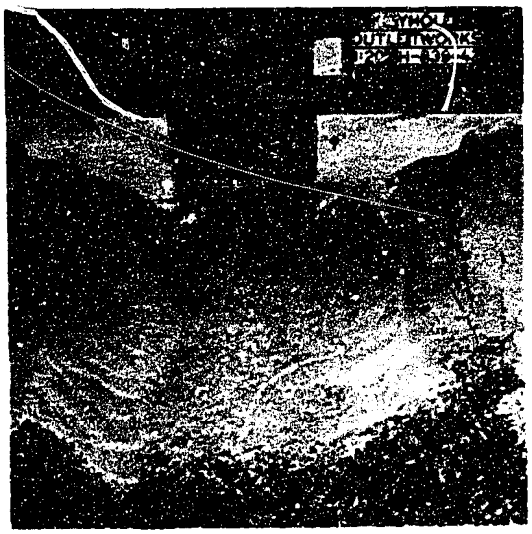
KEYHOLE DAM OUTLET WORKS
WATER SURFACE PROFILES
AT MAXIMUM RESERVOIR ELEVATION OF 4128.1 FEET
1 : 20 MODEL

FIGURE 20
REPORT HYD. 300

441



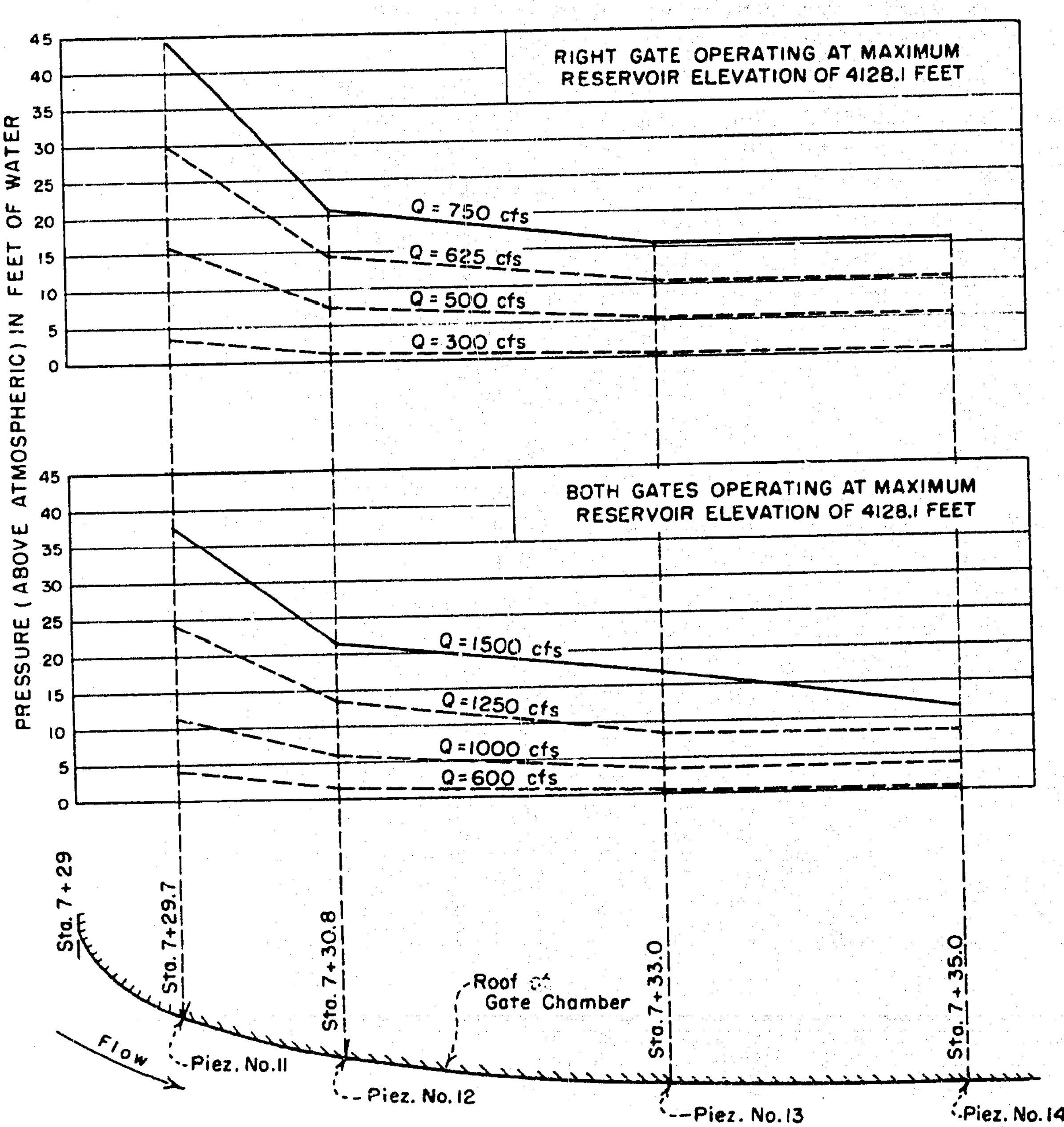
A. Bed arrangement before tests



B. Scour after right gate discharged 750 cfs. for 2.25 hours (prototype)

C. Scour after both gates discharged 1500 cfs. for 2.25 hours (prototype)

KEYHOLE DAM OUTLET WORKS
Depth of scour - Recommended basin
1:20 Model

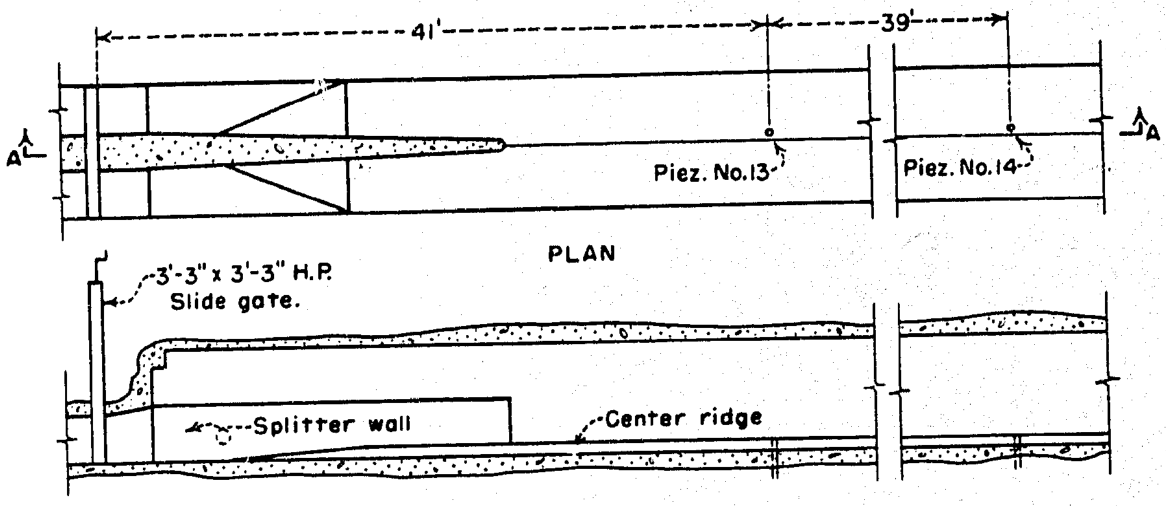


KEYHOLE DAM OUTLET WORKS

PIEZOMETRIC PRESSURES ON
BELLMOUTH ENTRANCE TO GATE CHAMBER

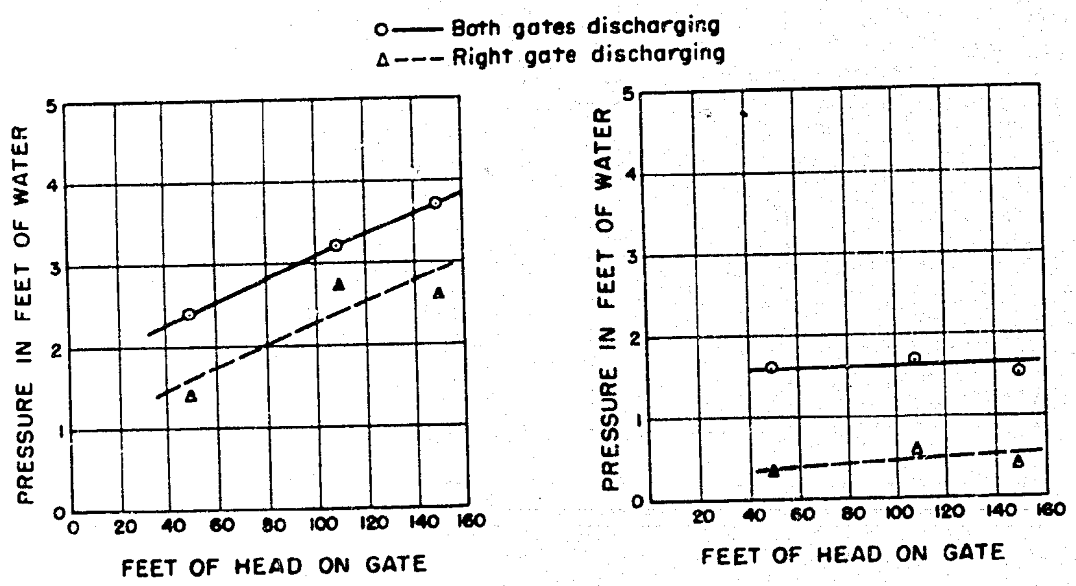
1 : 20 MODEL

FIGURE 23
REPORT HYD.338



SECTION A-A

PIEZOMETER LOCATIONS



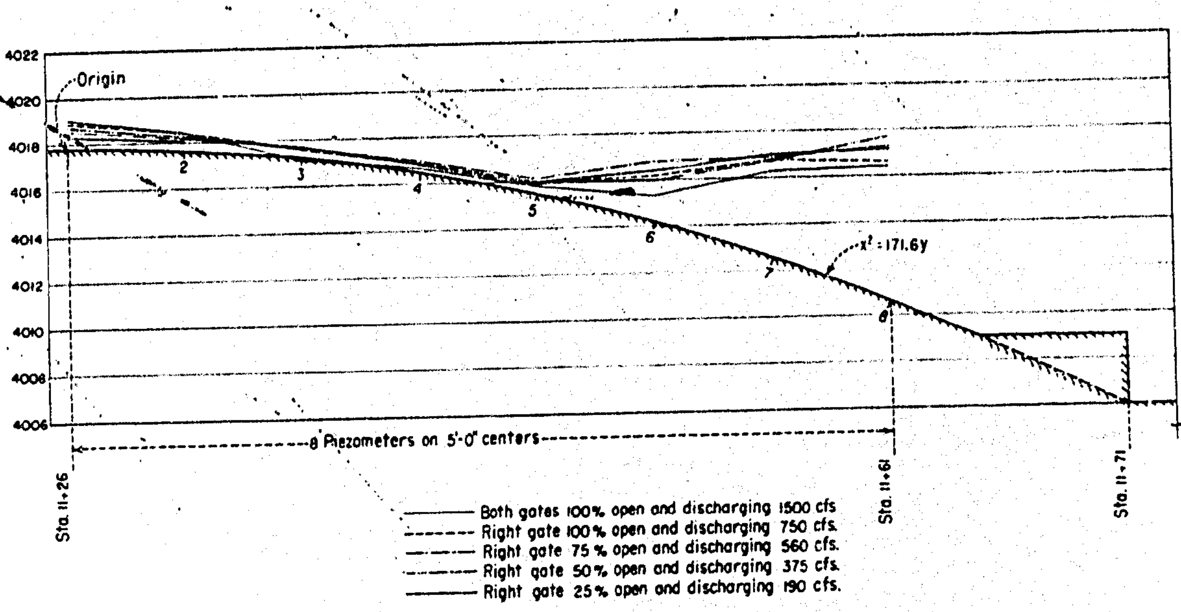
PRESSURE AT PIEZOMETER No.13

PRESSURE AT PIEZOMETER No.14

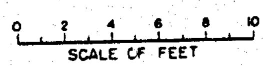
KEYHOLE DAM OUTLET WORKS

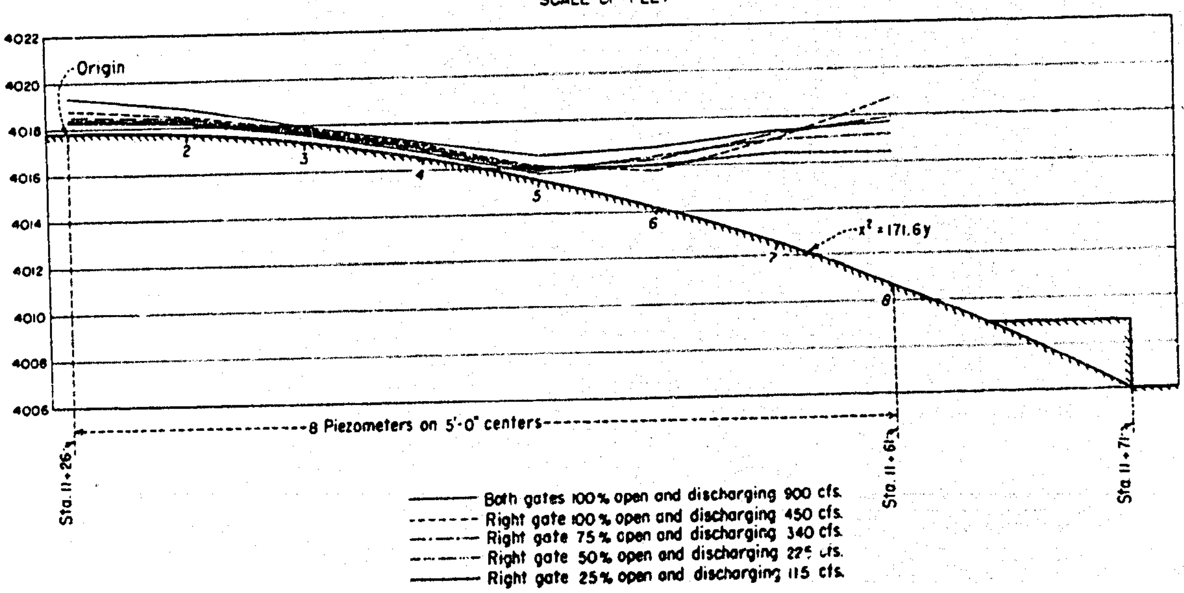
PROTOTYPE PRESSURES ALONG CENTER RIDGE

1:20 MODEL



RESERVOIR AT MAXIMUM ELEVATION OF 4128.1 FEET



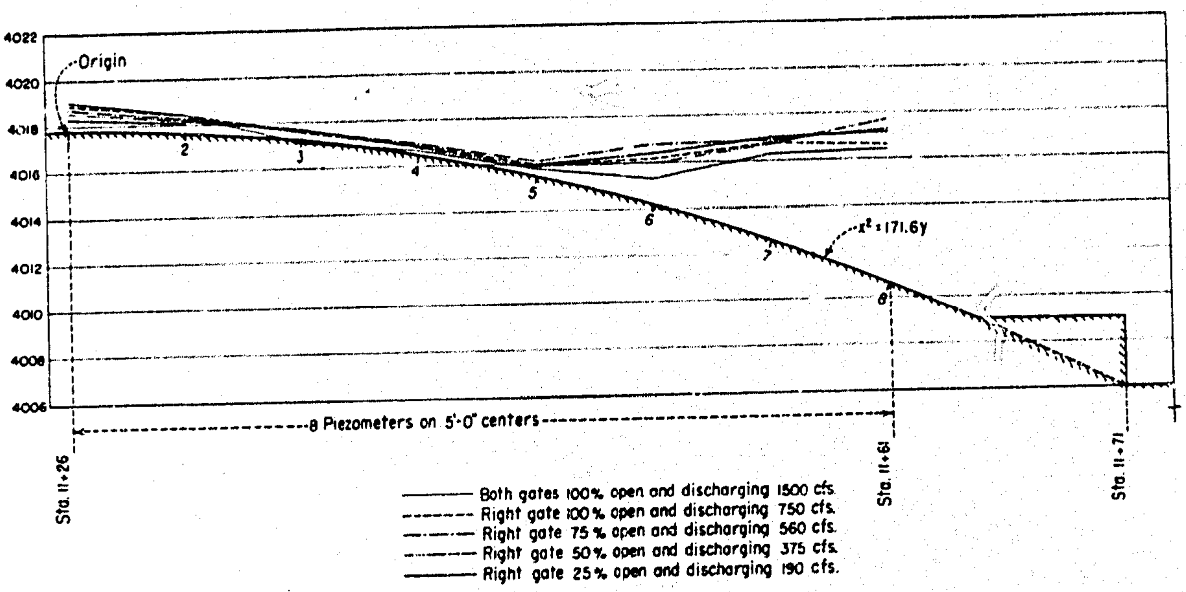


RESERVOIR AT NORMAL ELEVATION OF 4070 FEET

KEYHOLE DAM OUTLET WORKS

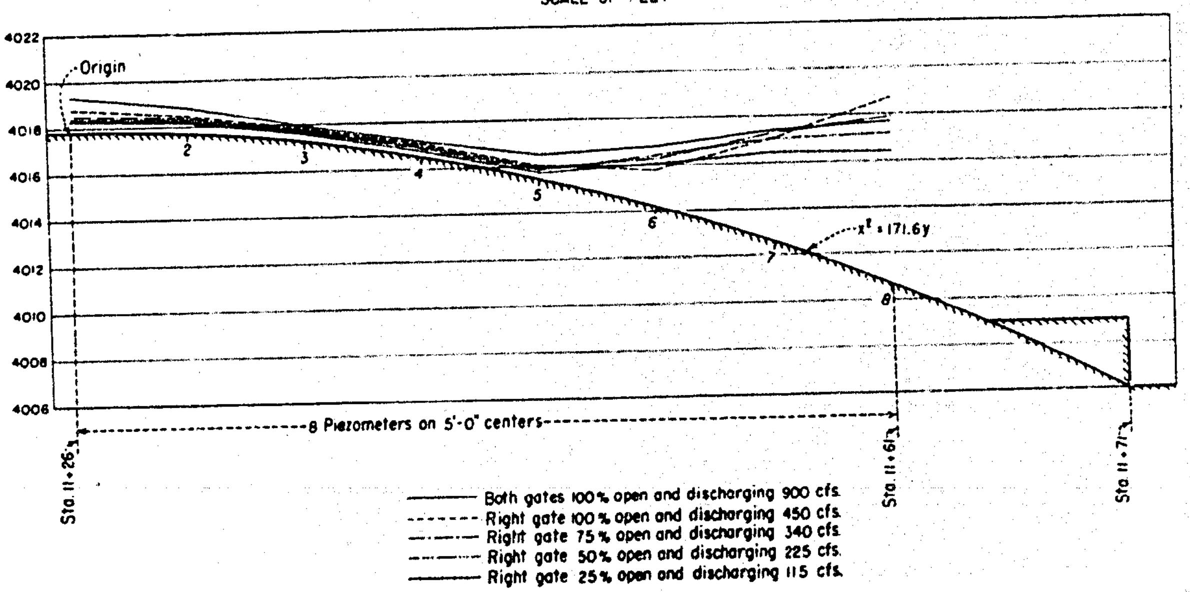
PIEZOMETRIC PRESSURES ALONG TRAJECTORY CURVE

1:20 MODEL



RESERVOIR AT MAXIMUM ELEVATION OF 4128.1 FEET

0 2 4 6 8 10
SCALE OF FEET

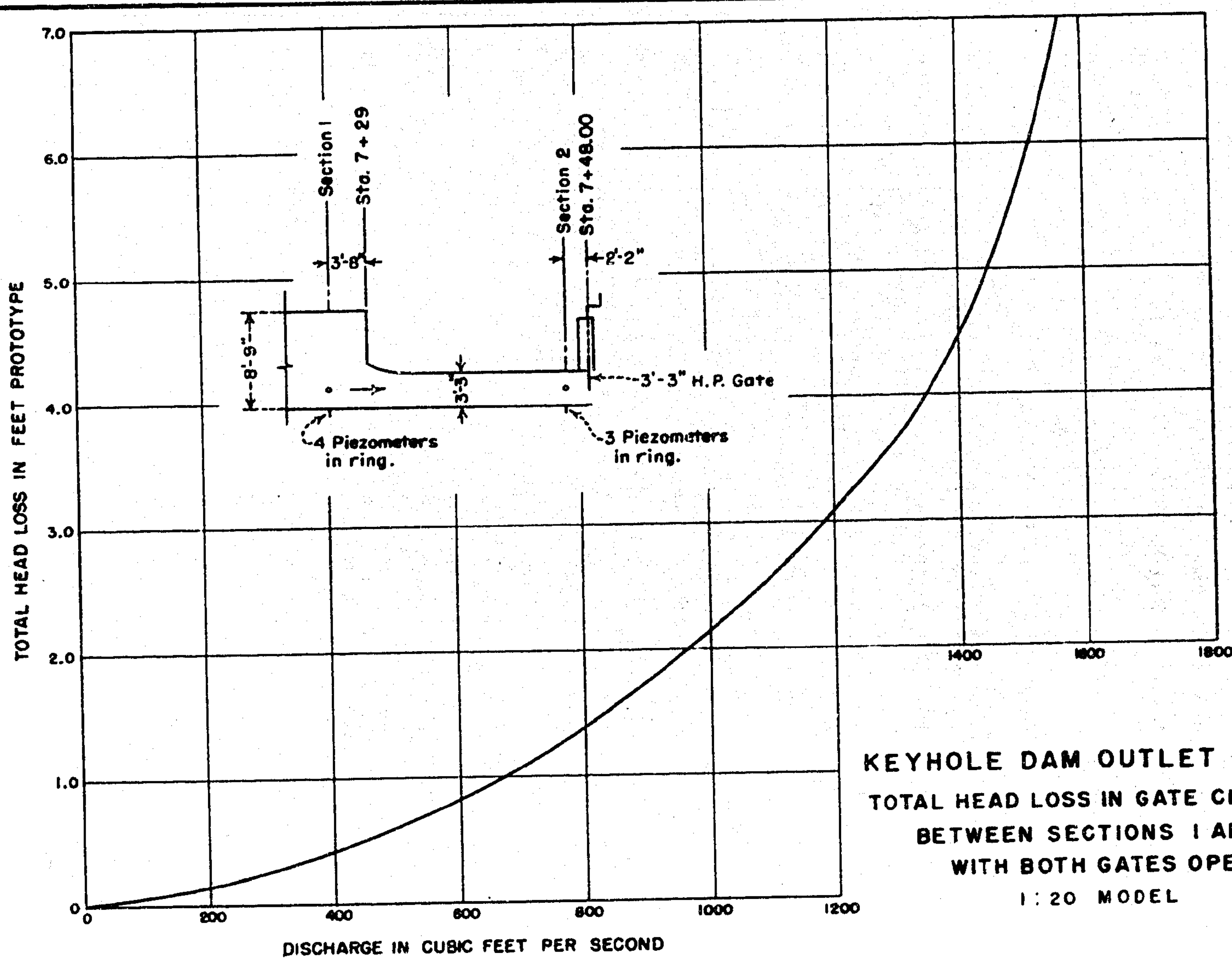


RESERVOIR AT NORMAL ELEVATION OF 4070 FEET

KEYHOLE DAM OUTLET WORKS

PIEZOMETRIC PRESSURES ALONG TRAJECTORY CURVE

1:20 MODEL



KEYHOLE DAM OUTLET WORKS

TOTAL HEAD LOSS IN GATE CHAMBER BETWEEN SECTIONS 1 AND 2 WITH BOTH GATES OPEN

1:20 MODEL

FIGURE 25
REPORT HYD.338

FIGURE 26
REPORT HYD. 338